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Communications Issues in Shipboard Telemedicine

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

OBJECTIVE

This study defines the specific communications capabilities of U.S. Navy ships and identifies operational problems and technical barriers prohibiting telemedicine on a wide scale. This information is needed so the transmission of medical data can be managed in conformance with shipboard capabilities and contingencies can be developed for the potential degradation of those capabilities. While communications requirements for telemedicine in the civilian sector continue to be defined and implemented on a limited basis, the Department of Defense (DoD) must also supply similar needs in hostile environments.

SCOPE

This report evaluates the effect current technology has upon the telemedicine aboard U.S. Navy ships while underway. The focus of this report covers current capabilities aboard U.S. Navy vessels for communication operations and for interfacing to existing infrastructure and future technologies. Identifying these capabilities will benefit the acquisition community and those who conduct requirement synthesis where technology proliferates and develops rapidly. This report identifies the communication assets of the fleet infrastructure ashore and at sea, and provides details of functional and technical requirements and possible near- and long-term solutions, enhancements, and recommendations.

REQUIREMENTS

SPAWAR Systems Command, under guidance from Commander in Chief, U.S. Pacific Fleet, and Commander in Chief, U.S. Atlantic Fleet, assembled a minimum set of essential U.S. Navy and Marine Corps requirements as part of the Theater Medical Information Program-Maritime (TMIP-M). Functional requirements included the following:

- **Medical Administration.** Patient demographic data and basic health information must be stored and tracked and available for recall as patients move geographically.
- **Radiation Health.** All periods of radiation monitoring for exposure must be documented and tracked.
- **Occupational and/or Environmental Health.** All occupational health elements are to be documented as required by DoD and Department of the Navy (DoN) directives.
- **Medical Encounters.** All health care encounters must be documented.
- **Supply.** A system is required to track the procurement, storage, and expenditure of medical materials within medical department spaces and storerooms.

Technical requirements include bandwidth requirements for different U.S. Navy telemedicine services. A bandwidth requirement has been developed for each telemedicine service, which can then be matched with the bandwidth capability of Navy communications resources.

RECOMMENDATIONS

This study has identified clear actions that will aid in the wider implementation of telemedicine in the U.S. Navy, Navy extensions, interfaces to the rest of the DoD, coalition forces, and the civilian sector. These actions include the following:

1. Provide an independent critical review of the existing disparate telemedicine solutions using laboratory and field-testing studies
2. Develop a telemedicine implementation roadmap spanning all U.S. Navy assets, and extending through joint coalition forces
3. Provide a mechanism for collecting telemedicine-related information that is developed in various technical communities and disseminate the information to all interested parties
4. Establish an impartial test bed to evaluate new technologies and systems. This test bed can examine feasibility under various operational scenarios (peacetime and wartime), and prioritize solutions. The test bed may also serve as a conduit for the transition of technology to the Fleet.
5. Identify a capable technical agent that can assist in program management, evaluate, demonstrate, and transition emerging technologies, and be actively involved in implementing all of the above recommendations.

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INTRODUCTION

Telemedicine is the electronic exchange of medical information from one site to another site. The primary goal is to improve health care for the patient and increase awareness for the health care provider. Further goals include reducing the cost of delivering medical care, improving the skills of health care providers, and enhancing the administration of the medical delivery system. Telemedicine includes transmission of voice, text, still images, video, and output from medical devices. It also allows access and manipulation of medical information in remote data banks. The information may need to be transmitted immediately or in a time-delayed mode. Many different technologies can be applied to the information transfer problem. Scientists and engineers who implement telmedicine systems consider bandwidth an important parameter. The required bandwidth depends on what type of data are transmitted and how quickly data need transmission.

Major telemedicine applications include teledermatology, telecardiology, telepsychiatry, teleradiology, telepathology, and tele-endoscopy. Each application has different requirements for data transfer. Telemedicine does not require live, streaming video. Most applications of telemedicine do not use live video. The simplest telemedicine system consists of a medical expert and a voice system (one-way or full-duplex). Other telemedicine implementations include the transfer of still images, medical history data, medical sensor output (e.g., electrocardiograms [ECGs]), and other information. Store and forward telemedicine stores data, compresses it, and then transfers it when the required bandwidth is available. This process works well for many applications, but is not adequate for others. Each telemedicine implementation has a different required communications data rate. A robust medical data and imagery transfer system is estimated to require 64 kbps full-time with 128 kbps on request. An available T1 bandwidth provides this data rate.

A critical goal for the U.S. Navy is to provide state-of-the-art healthcare for the warfighter, even when deployed to remote, inhospitable regions of the world. Evacuating a patient from a ship at sea could cost $100,000, depending on the particular situation; therefore, efficient use of medical evacuations is critical. Avoiding an unnecessary evacuation not only saves money but also allows sailors to return to full duty as quickly as possible and limits disruptions to the ship's operations. Full duty is especially important during hostile situations. The status of shipboard Medical Treatment Facilities (MTF) shows a ship's mission readiness. The next generations of U.S. Navy ships will have significantly reduced crew sizes, making each member of the crew more indispensable. Another significant benefit of shipboard telemedicine is the peace of mind it can bring to the sailor and his family, knowing that specialized medical care is available independent of ship deployment.

The following issues make shipboard telemedicine more problematic than land-based telemedicine:

- Communications system limitations (availability, data rates, coverage)
- Limited facilities
- Coordination with foreign governments
- Coordination between multiple services
- Security, patient confidentiality
- Problems/tradeoffs during military conflicts

The U.S. Navy Surgeon General's vision for telemedicine includes the following goals:

- Take advanced medical technology to the deckplate sailor
- Move information, not patients

This report uses many recent articles and documents that address medical services, telemedicine services, communications systems in general, communications systems in telemedicine services, and U.S. Navy telemedicine services and communications systems. Part of this effort was coordinated with Third Fleet personnel aboard USS *CORONADO* (AGF 11). Third Fleet's area of responsibility includes approximately 50 million square miles of the eastern and northern Pacific ocean areas including the Bering Sea, Alaska, the Aleutian Islands, and a sector of the Arctic. Third Fleet's Flag Ship, USS C*ORONADO*, fulfills five mission areas:

- Conflict deterrence
- Combat readiness for prompt and sustained combat operations at sea
- Command of joint U.S. forces
- Theater engagement
    - Continually trains U.S Navy and Marine Corps forces for their expeditionary warfare and mission
    - Rim of the Pacific (RIMPAC) exercises
- Innovation

The coordination provided direct feedback from experienced medical and military personnel on the state-of-the-art of available U.S. Navy telemedicine.

CORONADO, recently designated the first official sea-based battle laboratory of the U.S. Navy, is preparing for multitiered joint exercises in June 2001, when it will play the role of operational command and control. The Kernel Blitz Experimentation (KBX) will be a part of these exercises and will include experiments involving linkage of U.S. Navy and Air Force command and control systems, maritime Comand, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaisance (C4ISR) network-centric warfare, reach-back capability for commander-in-chiefs, coordination on consequence management, and Marine Corps warfighting concepts. The Joint Medical Operations/Telemedicine (JMO-T) portion of KBX will allow reach-back capability for *CORONADO* to the Army Consequence Management Mission Command, located at Ft. Lewis, Washington, and responsible for the Pacific Command. Consequence management is the assurance of preparation for chemical/biological warfare.

BACKGROUND

Modern telemedicine has existed and evolved as a Next-Generation Enterprise since the 1950s. Over 40 years ago, closed-circuit television broadcast major surgical procedures to audiences at national medical society meetings. In 1965, physicians in Europe participated in an open-heart surgery performed by Dr. Michael DeBakey in Texas. COMSAT's Early Bird, the world's first intercontinental communications satellite, transmitted the real-time conversation.

A national conference on telemedicine was held in 1973. By the late 1980s, telemedicine delivered healthcare to remote parts of Norway. Prisons, cruise ships, the military, space programs, offshore oil rigs, and rural areas have implemented telemedicine systems.

The international maritime satellite (INMARSAT) has been used in many deployable telemedicine applications. The U.S. Army used INMARSAT to transmit teleradiology images from the Virgin Islands after Hurricane Hugo hit in March 1990. During the Persian Gulf War, the U.S. Army used an INMARSAT terminal to transmit computerized tomography (CT) images to the United States for expert consultation. In 1993, U.S. Army medical units in Somalia used the Remote Clinical Communications System (RCCS) to transmit digitized CT images from a portable INMARSAT terminal. Other satellite systems have been used in Haiti (1994), Macedonia and Croatia (1995), and Bosnia (1996).

Telemedicine has been helpful during natural disasters such as hurricanes and earthquakes. The National Aeronautics and Space Administration (NASA) telecommunications technology assisted with disaster relief after Mexico City's 1985 earthquake. Medical relief organizations used NASA's Advanced Communication Technology Satellite to support their rescue and relief efforts. The U.S./U.S.S.R. Space Bridge Project used commercial satellite communications to link Armenian hospitals with U.S. medical centers after the Armenian Earthquake of 1988. A section of this report addresses the issues of telemedicine applications during disaster situations in more detail.

The Mermaid Project, a European Union telemedicine program set up to provide long-distance medical consultation for maritime workers, supports telemedicine for the Merchant Marine. It is a multilingual service that supports the estimated 1.5 million worldwide merchant marines and other maritime employees. The Mermaid Project used INMARSAT A, B, C, or M satellite communications (SATCOM) systems that provide varying data rates. The systems can be easily upgraded as terminals when higher data rates become available.

Telemedical care onboard U.S. Navy ships is closely related to the enhancement and evolutionary path of communications technologies. These technologies must be properly implemented and efficiently applied to better cover the healthcare needs of warfighters during war or peace.

MEDICAL COMMUNICATIONS

A medical communication is any communication that helps medical personnel at all levels in their patient evaluation, diagnosis, treatment, follow-up procedures, and any other medical assistance required by the patient. This assistance can take place ship-to-ship or ship-to-shore. Most medical service departments aboard U.S. Navy ships are headed by independent duty corpsmen (IDCs) who are responsible for all aspects of primary health care delivery. Computer-assisted clinical algorithms have helped in the diagnosis and treatment of some medical conditions, but communication of corpsmen with physicians and the linkage of physicians with other physicians still remains a very

important aspect of medical treatment. The nature and frequency of these communications must be classified to address the more technical issues of telemedicine.

This section provides information obtained from a 9-month study (Nice, 1987) of all U.S. Navy surface ships, Pacific Fleet submarines, and all ships of the Military Sealift Command (MSC). The study documented the diagnoses that required medical communications or evacuations and their frequency. Figure 1 shows that the necessity to establish medical communication is higher for U.S. Navy surface ships with an IDC than among ships with a physician aboard. The rate of medical communication required per 1000 patient visits had a mean of about 4.4 for corpsmen and about 0.7 for physicians. Figure 2 shows the frequency of these calls. The graph is divided into ship-to-shore and ship-to-ship calls and also into calls made either by a corpsman or by a physician. An important result in this study shows that independent duty corpsmen in combatant ships have a greater need for medical communications, and in most instances (70%), contact was made with another ship rather than with shore facilities. The medical communications originating from surface ships with a physician aboard were fewer and were made to shore facilities in most cases (95%) rather than to other ships.

Primary communication modes for medical purposes included radio telephone (39%) and e-mail (36%). Approximately 62% of these two communication modes were established with other ships within a median distance of 10 miles. Most (>60%) of these communications resulted in patients being evacuated off the ship. The probability of a medical evacuation (MEDEVAC) following a medical communication did not have a significant variation between physicians and corpsmen. Figures 3 and 4 show the rate of MEDEVACs by ship type and MEDEVAC type (ship-to-ship or ship-to-shore), respectively. Figure 4 shows that 468 (63%) of the transfers were made to a shore MTF. Another important result of this study is that ships with physicians aboard MEDEVACed their patients to shore MFTs, and that combatant class ships with only IDCs aboard usually MEDEVACed their patients to ships with larger MTFs.

Medical conditions requiring communication included fractures and lacerations (31%), digestive problems (17%), abdominal or chest pains (10%), infectious diseases/hepatitis (8%), mental disorders (6%), genitourinary (5%), and nervous system and sense organs (5%). A more detailed description of diagnoses and corresponding incident rates is presented later in this section. Overall, 752 medical communications were established and 743 MEDEVACs were performed during this study that included 396 U.S. Navy ships and submarines and 54 ships of MSC. A U.S. Navy ship initiates an average of two medical communications per year and two MEDEVACs per year. Ships with a physician aboard average 1.5 MEDEVACs per 1000 patient visits; those with an IDC aboard average 3.5 MEDEVACs per 1000 patient visits.

MTF capabilities aboard a given ship vary with ship type and size. Capabilities are sometimes inadequate for the proper health care of a patient, requiring the transfer of the patient to a larger ship MTF or to a shore facility. Alternatively, more qualified medical personnel or more specialized medical equipment must be transferred to the patient's location. These evacuations or transfers are usually by helicopter. A helicopter evacuation costs $100,000 and directly affects the ship's mission readiness. For all the above reasons, the number of evacuations must be reduced without sacrificing the health care of the patient. Figure 5 shows the percentage of MEDEVACs by ship class to a shore MTF (63%) or to another ship's MTF (37%). The same study in reference 1 found that in 28% of the cases, the requirement for a MEDEVAC could have been avoided if better telecommunication capabilities had been available. Figure 6 shows which telecommunication resources would have improved medical services.

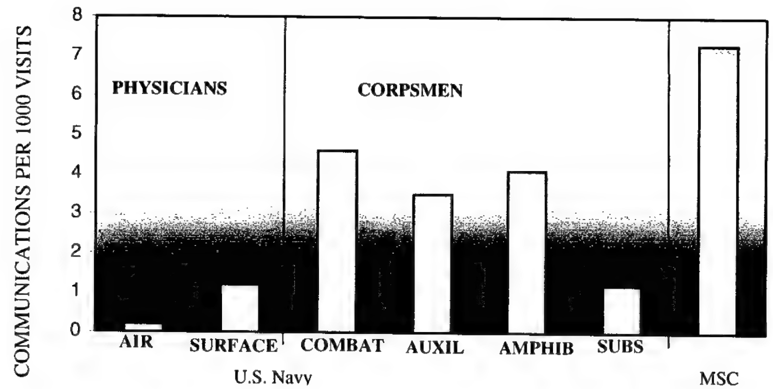

Figure 1. Rate of medical communications at sea.

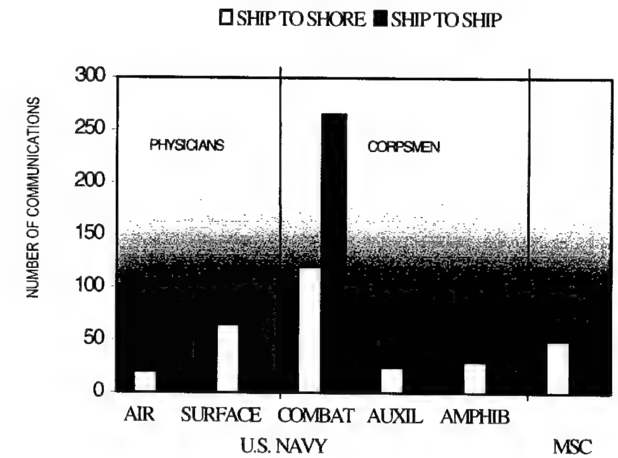

Figure 2. Communications: ship-to-ship vs. ship-to-shore.

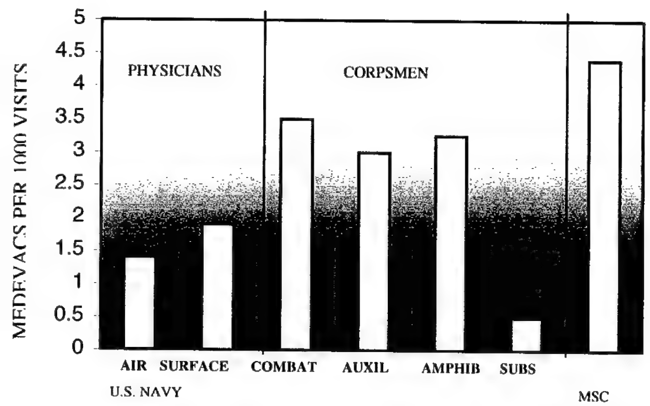

Figure 3. Rate of MEDEVACs by ship type.

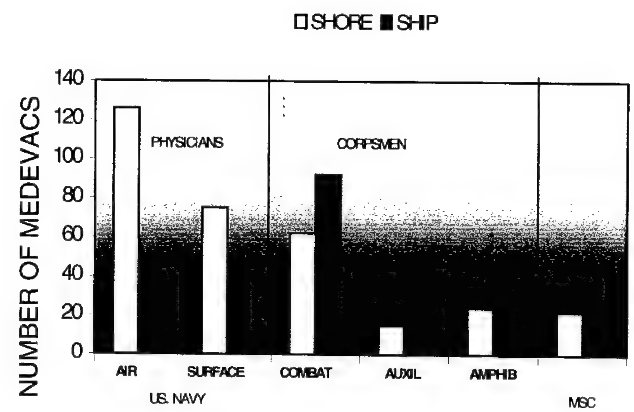

Figure 4. Ship-to-ship vs. ship-to-shore MEDEVACs.

CAPABILITIES OF MEDICAL TREATMENT FACILITIES

The health care provided by MTFs onboard U.S. Navy ships plays a very important role in maintaining mission readiness. The *Fleet Marine Force Manual* (FMFM) 4-50, Health Service Support (HSS), defines this function as to "provide the medical and dental care and treatment required to maintain, preserve, and restore the combat power of the force". These functions are categorized as follows: (1) Health Maintenance, (2) Casualty Collection, (3) Casualty Treatment, (4) Temporary Hospitalization, (5) Casualty Evacuation, and (6) Preventive Medicine.

The information in this section was obtained primarily from the *Medical Contingency Fact* Book (Bureau of Medicine and Surgery, 1999) and provides an overview of the medical capabilities of surface ships and carriers including Hospital Ships (T-AH): Mercy Class; Aircraft Carriers (CVN): Enterprise, John F. Kennedy, Kitty Hawk, and Nimitz Class; Amphibious Command Ships (LCC): Blue Ridge Class; Amphibious Assault Ships (LHA and LHD): Tarawa and Wasp Class; Amphibious Transport Dock (LPD): Austin Class; and Dock Landing Ships (LSD): Harpers Ferry, Anchorage, and Whidbey Island Class. AGF, AOE, and AS belong to the Auxiliary Ship Class.

Table 1 shows the MTF capabilities of each class of ship including Medical Corps (MC), Dental Corps (DC), Military Sealift Command (MSC), Nurse Corps (NC), Hospital Corpsmen (HM), Dental Technicians (DT), Ward Beds, Operating Rooms (ORs), Intensive Care Unit (ICU), and Quiet Beds.

U.S. Navy Hospital Ships are the largest and most sophisticated MTFs, with more than 60 physicians, a CT scanner, and blood storage facilities, 12 ORs, and approximately 1000 beds; the MTFs aboard aircraft carriers usually have six physicians, one OR, and an average of 50 beds; large amphibious, auxiliary, and combat ships have one physician; the LHA and LHD have four operating rooms with more than 50 beds. All these ships have x-ray and other laboratory facilities; smaller surface ships and submarines usually have one IDC and very little equipment.

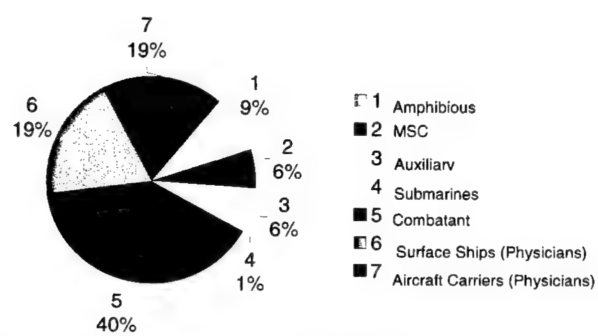

Figure. 5. Percentage of MEDEVACs in the U.S Navy by ship class.

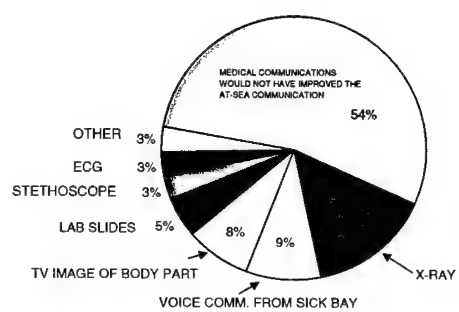

Figure 6. Telecommunication technologies that would have significantly improved field medical consultation.

Table 1. MTF capabilities of surface ships and aircraft carriers.

Ship Class	MC	DC	MSC	NC	HM	DT	Ward Beds	ORs	ICU Beds	Quiet Beds
AGF	1	1			5**	2	12	1		
AOE	1	1			4**	2	13			
AS	1	3	1		13	8	24	1	1	4
CV	6	5	5*	1	33***	13	52	1	2	4
CVN	6	5	5*	1	33***	14	52	1	2	4
LCC	1	1			12–15**	3	20			4
LHA	1	1	1		16**	3	45	4	15	4
LPD	1	1			6**	3	6-8	0		2
LSD	1	1			7*	3	6	0		2
LHD	2	1	1		17	4	45	4	15	6
T-AH	66	4	20	168		11	500[(a)]	12	100[(b)]	400[(c)]

* Includes one physician Assistant
** Includes one Independent Duty Corpsman
*** Includes two Independent Duty Corpsmen
(a) Minimal Care Beds
(b) Intensive Care Unit Beds
(c) Intermediate Care Beds

As mentioned previously, the average cost of a MEDEVAC operation is about $100,000; at a monthly average of 83 MEDEVACs, the annual cost might be around $100M. This cost does not reflect the effect on the ship's mission and operational readiness and the associated cost for a ship to remove itself from an operational readiness state, perform a MEDEVAC operation, and return to an operational readiness state. The process of MEDEVAC is a very expensive operation and directly affects the combat readiness status of ships at sea. Any efforts to reduce the number of MEDEVACs will substantially reduce cost. Telemedicine technology reduces the cost of operation and improves the mission readiness of the ships.

TELEMEDICINE TECHNOLOGIES AND SERVICES

This section describes the telemedicine technologies currently available aboard U.S. Navy ships and the specific technical requirements, such as bandwidth, for each telemedicine scenario. Part of the information provided was obtained from a study conducted by the Naval Health Research Center (NHRC) (Martinez and Smith, 1996) to determine the use of various telemedicine technologies. (Several figures and tables presented in reference 3 were modified and incorporated into this report; some of the concepts and descriptions were also used in this report.) In the study, a group of 25 IDCs with experience aboard U.S. Navy surface ships was asked to rate the technologies in table 2 with the 28 patient conditions in table 3. Table 3 also includes incidence rates based on data collected from 2725 crew members aboard four destroyers.

Network and telecommunication architectures must be defined to allow the transmission of multimedia medical information. Figure 7 shows a telemedicine network scenario that supports the operation of MTF facilities aboard U.S. Navy ships and their requirement to establish communication with other ships and shore facilities. This figure also shows the line-of-sight (LOS) and SATCOM systems communicating between ships and naval shore facilities. In this architecture, SPAWAR Systems Center, San Diego (SSC San Diego) serves as a node to send multimedia telemedicine information from the ships to a Naval Medical Hospital through the Internet. The architecture also exchanges telemedicine information between a smaller ship and a larger ship with greater MTF resources.

To describe the multimedia telemedicine services available onboard U.S. Navy ships, the types of information exchanged between U.S. Navy units and facilities must be defined. These different types of information are defined as multimedia object classes and described in table 4.

Table 2. Ranking of medical telecommunications technologies.

No.	Technology
1	Fax
2	E-mail
3	Phone
4	Speaker-phone
5	Radiophone
6	Oscilloscope
7	Stethoscope
8	Sphygmo-meter
9	Slides
10	Body still images
11	Otoscope
12	Ophtalmo-scope
13	Video
14	X-ray
15	Dental x-ray

Table 3. Diagnoses with corresponding incidence rates.

No.	Diagnosis	Rate
1	Acute upper respiratory infection	0.818
2	Back disorders	0.540
3	Dental examination	0.488
4	Streptococal sore throat and scalatinal	0.395
5	Viral infection	0.349
6	Cardivascular/respiratory screening	0.278
7	Neoplasms screen (pap/pelvic)	0.260
8	Disease due to viruses	0.239
9	Soft tissue injury /musculoskeletal trauma	0.235
10	Noninfective gastroenteritis/colitis	0.235
11	Acute pharyngitis	0.222
12	Sprains/strains of ankle feet	0.211
13	Effects of external cause (motion sickness)	0.209
14	Diseases of hair/hair follicule	0.208
15	Disorders of urethra /urinary tract	0.204
16	Contact dermatits/other eczema	0.191
17	Disorders of external ear	0.184
18	Injury of eye	0.180
19	Acute sinusitis	0.167
20	Gastritis/duodenitis	0.162
21	Sprain/strain of back/neck	0.155
22	Disease of sebaceous glands	0.153
23	Internal derangement of knee	0.149
24	Candidiasis	0.136
25	Dermatophytosis	0.134
26	Phlebitis of thrombophlebitis	0.11
27	Viral hepatitis	0.10
28	Mental/behavioral problems	0.10

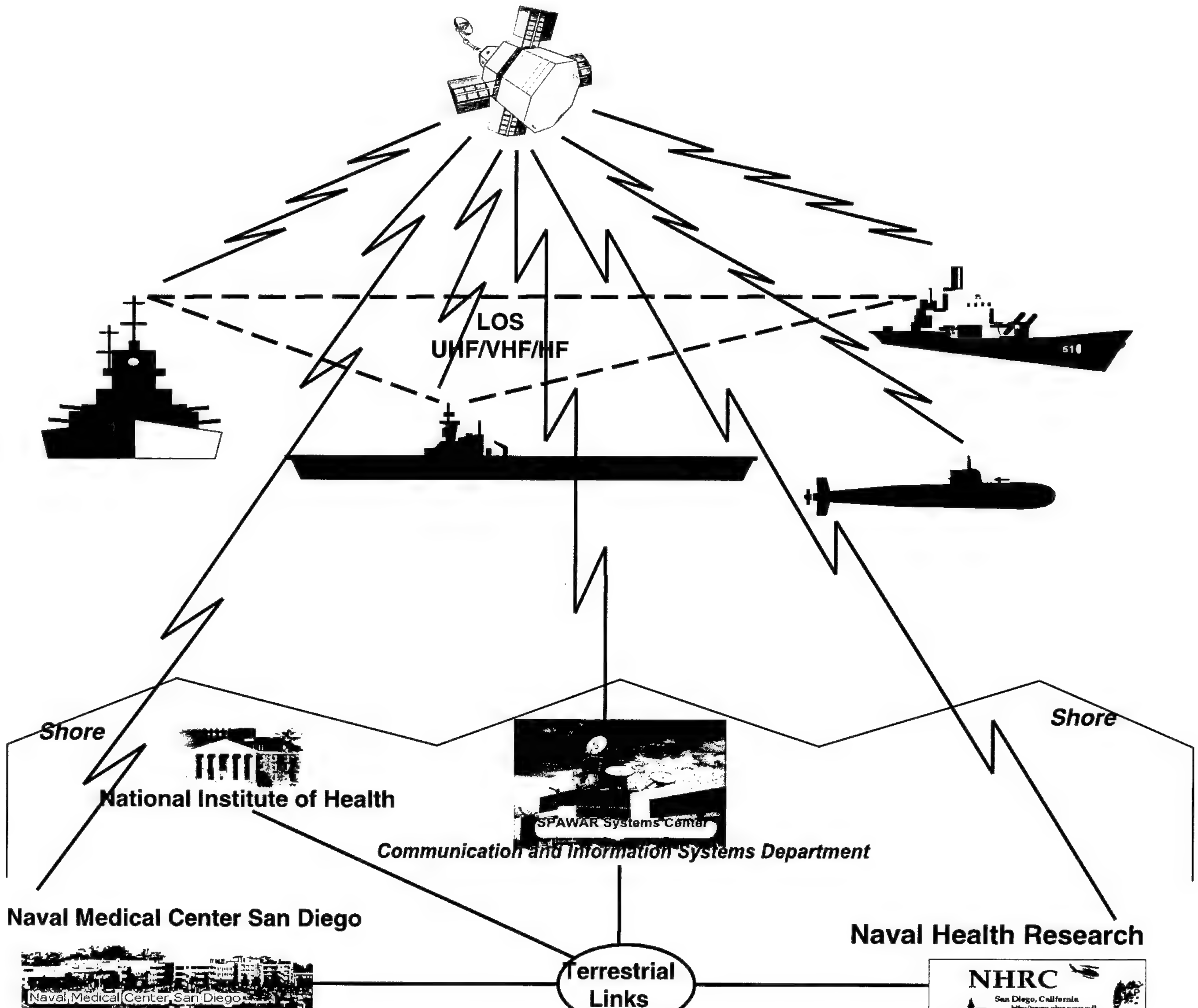

Figure 7. Telemedicine network to support U.S. Navy MTF.

Table 4. Definitions of multimedia object classes used in telemedicine applications.

Object Class	Description
Graphical User Interface (GUI)	Tools that enhance the human–computer or human–equipment interface during a telemedicine session. The GUI at the telemedicine workstation includes pointer devices, icons, menus, buttons, keyboard, audio, and video information, etc.
Video	Video sequences at the telemedicine workstation. These sequences can be real-time or playback sequences in a digital format. Different compression techniques, such as MPEG, AVI, or quicktime are used. These video sequences can also be generated from a VCR or in CD formats.
Audio	Audio sequences at the telemedicine workstation. These sequences can be 8-bit or 16-bit digitally encoded audio sequences using standard telephone CODEC conversions. Audio is typically full duplex in a workstation and can be stored as a digital file and synchronized with video sequences in a multimedia environment.
Image Annotation	User commands that allow medical staff to manipulate and annotate an image during a telemedicine session. Annotation commands may include fixed pointing, box outlining, or freehand drawing. These graphical objects can be represented and packaged into a 400-byte packet. For delivery times of less than 200 milliseconds (real-time), the bandwidth requirement for this object is 2 Kbps.
File Stream	Flow of packets between workstations that represent audio, image, video, image annotation, text, security, management and control, and mouse movement information. These objects inherit the format of the type of object they transfer.
Synchronization	Algorithms and procedures for synchronizing different types of multimedia information such as between audio and video. These objects use semaphores, time-stamping, and protocols as synchronization algorithms between objects.
Multimedia Buffer	Buffers that must be managed to acquire, receive, and transfer objects between telemedicine workstations.
Security	Several types of security information required for the management and operation of security services in the telemedicine systems.
Management and Control	Data types that allow for the control and management of the telemedicine workstations among multiple users during telemedicine sessions.
Evaluation	Parameters and criteria measured for evaluation of telemedicine system performance.
Performance	Parameters and criteria that measure telemedicine system performance. Some examples of this object are length of message, frequency, bandwidth, type of message object, type of communication used, etc. Some interfacing with ship's communication resources may be required.
Textual	Textual information required to describe patient's medical condition, treatment, diagnosis, etc. This object can be linked to other object classes such as x-rays, EKGs, vital signs, etc.
Vital Signs	Patient's medical information such as temperature, blood pressure, heart rate, etc. This object class can also be linked to other objects such as textual and image object classes.

TELEMEDICINE MILITARY APPLICATIONS DURING DISASTER SITUATIONS

This section examines some instances where U.S. armed forces used government and commercial telemedicine technologies during disaster situations. These examples demonstrate the viability and effectiveness of a telemedical theatre. When a severe earthquake struck Armenia in 1988 (Rayman and Russel, 1992), a telecommunication system called Spacebridge was developed and integrated with the then-current Soviet system. Spacebridge linked Armenia with four medical centers in the U.S through land-lines, international and domestic satellites, and two Earth stations in Armenia and Roaring Creek, Pennsylvania. This network could transfer one-way video, two-way sound, and facsimile. The program demonstrated satellite and land communications in telemedicine that could be used for military disaster relief.

When Hurricane Hugo hit the Virgin Islands in 1990 (Garshnek and Burkle, 1999), the Alabama Army National Guard mobile army surgical hospital (MASH) deployed to St. Croix. MASH used a computerized radiography scanner, a digitizer, and a INMARSAT terminal to transmit digitized radiographic images to Walter Reed Army Medical Center (WRAMC) in Washington, DC., and Dwight D. Eisenhower Army Medical Center in Augusta, Georgia.

In 1992, the U.S. sent aid to Somalia to relieve the devastation, famine, and spread of infectious diseases during a civil war. During this humanitarian effort, the Remote Clinical Communications System (RCCS) was deployed to transmit digitized CT images and voice messages from a portable INMARSAT terminal to WRAMC. The RCCS was a low-bandwidth (9600 bps) telecommunications system that was essential in facilitating neurosurgical and neuroradiologic consultations.

In 1994, a U.S. team was sent to Haiti to restore power to President-Eect Jean-Bertrand Aristide. A 56-Kbps maritime satellite linked to a 56-Kbps commercial line at WRAMC was initially used. The Army Space Command later allocated a T1-/VSAT (very small aperture terminal) with a 1.54-bps bandwidth that linked to NASA's Advanced Commnication Technology Satellite (ACTS) system. A full-motion video link was established between the field hospital in Haiti and WRAMC. This system was used for video teleconferencing, which included video-enabled diagnostic equipment, including otoscopes, ophthalmoscopes, and dermscopes. Communication with this system resulted in one oral surgery, one neurology, and three dermatology consultations. During this deployment, the most frequently used consultants were dermatologists, radiologists, orthopedists, and hand surgeons.

In 1996, DoD's Operation Primetime III, an extension of Operation I and II, provided Bosnia with theatre telemedical support. This system connected army field physicians with doctors at five U.S. locations: Washington, Texas, California, the District of Columbia, and Hawaii. In forward-deployed frontline care centers, physicians could transmit x-rays, ultrasound, color Doppler, CT scans, and even full video/sound motion videos to remote medical facilities for consultation using commercially available technologies. This system was also used to access patient medical records, track patient evacuations, and for digitized medical logistics support, teledentistry, online clinical information, and simple e-mail. This system initially relied on Asynchronous Transfer Mode (ATM) technology, but in its later stages, was changed to an Integrated Services Digital Network (ISDN)-based system that used the Internet. The worldwide access telemedicine hub was at the Landstuhl Regional Medical Center in Germany, and communication nodes were installed at the combat support hospitals in Hungary and Bosnia.

Table 5. U.S. military disaster response.

Year	Project Response	Technologies Used	Communication Capabilities
1988	Spacebridge (U.S.S.R)	INTEL-SAT, COMSAT	1-way video, 2-way sound, facsimile
1990	Hurricane Hugo (Virgin Islands)	INMARSAT, land-lines	CT
1992	Somalia	INMARSAT, land-lines	CT
1993	Primetime I (Macedonia, Croatia)	Orion satellite	CT, images
1994	Hati	INMARSAT, ACTS, land-lines	CT, video, images, digital devices
1995	Primetime II (Croatia)	Orion satellite, ATM	CT, images, ultrasound, color Doppler
1996	Primetime III (Bosnia)	Orion satellite, ISDN	CT, images, ultrasound, color Doppler, e-mail

COMMUNICATIONS RESOURCES

This section provides a summary U.S. Navy communications systems and describes the characteristics of the prominent communications systems. Much of this information was extracted from the SSC San Diego document on the Communications Support System (CSS) Channel Access Protocol Specification (NRAD, 1995a), the User Profile Document (NRaD, 1995b), and the draft report previously cited (Martinez and Smith, 1996). Modern and joint force operations require assurance that information will be exchanged quickly, and that its integrity will be preserved under transmission through an intermediate channel. This exchange includes information gathering, processing, and dissemination among heterogeneous computer operating systems across the U.S. Navy and other entities. An Integrated Command and Control, Communications, Computer and Intelligence (IC4I) architecture is currently being developed under the DoD Technical Architecture Framework for Information Management (TAFIM). This architecture will provide information structure, information processing (command and control), information transfer (communications), and related control and management functions.

Communications systems described in this section are characterized based on bandwidth, error rate, robustness, and delays. Nine categories have been defined to test and evaluate commercial off-the-shelf (COTS) and government off-the-shelf (GOTS) standard interface profiles:

- Broadband Terrestrial Networks represented by ATM switching and Synchronous Optical Network (SONET) transmission systems in the High-Data-Rate Mobile Internet (MONET) laboratory at SSC San Diego
- Extremely High Frequency (EHF) Low Data Rate (LDR) SATCOM
- EHF-1, Medium Data Rate (MDR) SATCOM (future capability)
- High-Frequency (HF) radios
- L-band SATCOM, represented by INMARSAT system capabilities that are installed on many U.S. Navy ships
- Ku-band commercial Super High Frequency (SHF) SATCOM 1
- X-band military SHF SATCOM
- Ultra-High Frequency (UHF) LOS radios
- UHF SATCOM

Table 6 provides a qualitative summary of the characteristics of each system. Figure 8 shows a communications scenario where the systems just described are used. Table 7 shows the bandwidth capacities by ship class. Tables 8 through 13 describe the Beyond Line-of-Sight (BLOS)/Line-of-Sight (LOS) and SATCOM capabilities of amphibious, auxiliary, and surface combatant U.S. Navy ships.

Table 6. Characteristics of U.S. Navy communications resources.

Resource	Bandwidth	Delays/ Latency	Error Rate	Robustness
Broadband Terrestrial	High	Low–Medium	Low	High
EHF LDR	Low	Low–Medium	Low	High
EHF MDR	Low–Med	Low–Medium	Low	High
HF	Low	Low–Medium	High	Low
L-band Commercial INMARSAT	Low–Medium	Low–Medium	Low–Medium	Low
Ku-band Commercial SHF SATCOM	Low–Medium	Low–Medium	Low–Medium	Low
X-band Military SHF SATCOM	Low–Medium	Low–Medium	Low–Medium	Medium
UHF/VHF/ LOS	Low	Low–Medium	Medium	Medium
UHF SATCOM	Low	Low–Medium	Medium–High	Low

Table 7. Bandwidth capacity by ship class.

Ship Category	Ship Class	Total Bandwidth RX (Kbps)	Total Bandwidth TX (Kbps)
Surface Combatant	Aircraft Carrier (CV)	1029	999
	Cruiser (CG)	798	798
	Destroyer (DD)	165	165
	Frigate (FFG)	141	141
Amphibious	LHA	694	626
	LPD	121	103
	LST	111	91
	LSD	114	101
Auxiliary	AOE	111	98
	AOR	92	80
	AD	90	74

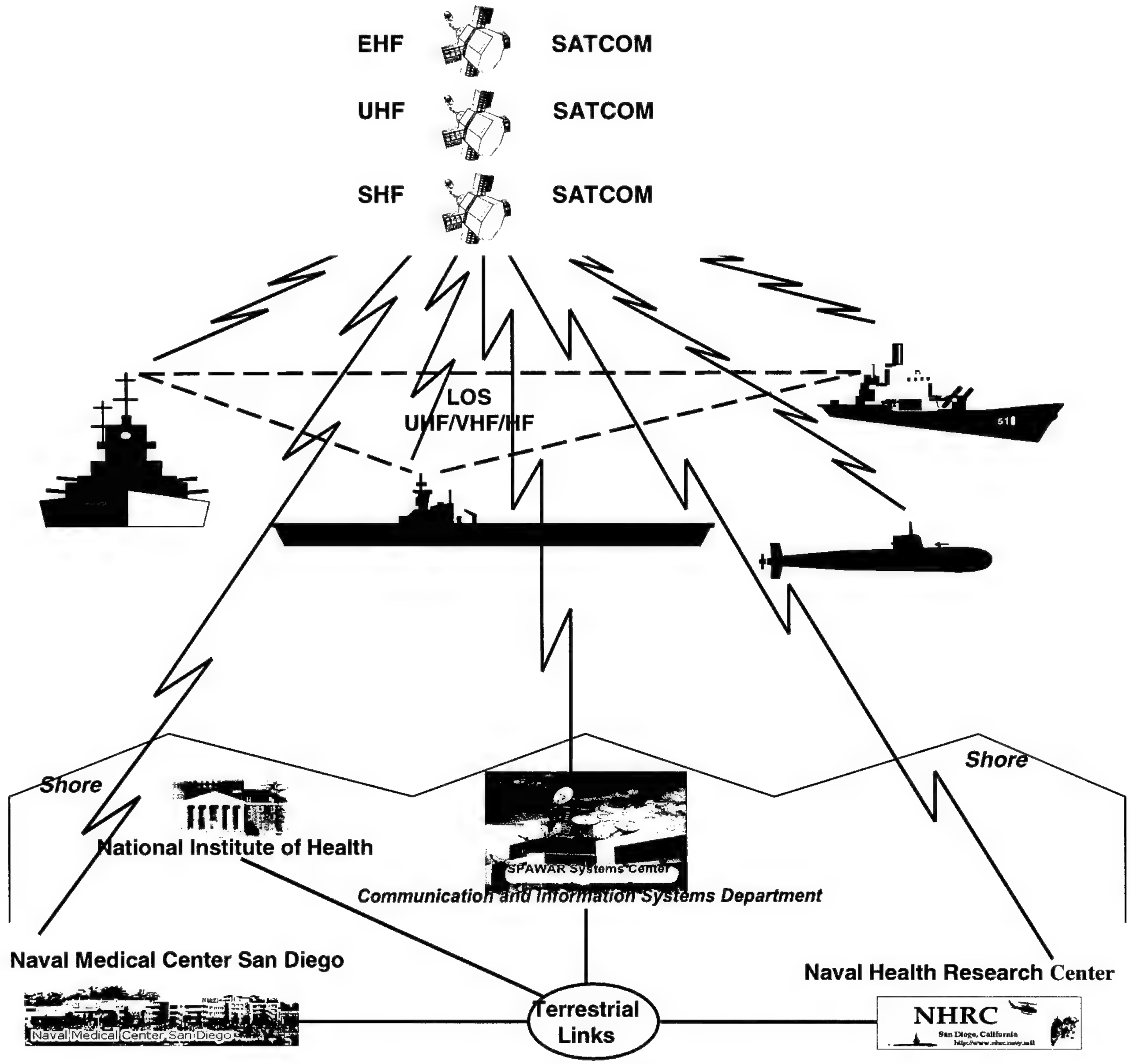

Figure 8. Satellite communications to support U.S. Navy MTF.

Table 8. BLOS/LOS requirements for amphibious ships.

Ship Class	Characteristics	BLOS/LOS (Kbps)					
		UHF WSC-3 RX/TX	UHF URC-93 RX/TX	VHF GRC RX	VHF GRT/R RX/TX	HF/MF/ LF RX	HF TX
LHA	Quantity	0	0	0	0	2.9	0
	Unit rate	0	0	0	0	2.4	0
	Aggregate	0	0	0	0	69.9	0
LPD	Quantity	7	0	1	1	16	10
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	67.2	0	2.4	2.4	38.4	24
LST	Quantity	5	0	1	1	16	9
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	48	0	2.4	2.4	38.4	21.6
LSD	Quantity	7	0	1	1	9	5
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	67.2	0	2.4	2.4	21.6	12

Table 9. BLOS/LOS requirements for auxiliary ships.

Ship Class	Characteristics	BLOS/LOS (Kbps)					
		UHF WSC-3 RX/TX	UHF URC-93 RX/TX	VHF GRC RX	VHF GRT/R RX/TX	HF/MF/ LF RX	HF TX
AOE	Quantity	7	0	1	1	8	4
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	67.2	0	2.4	2.4	19.2	9.6
AOR	Quantity	6	0	1	1	8	4
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	57.6	0	2.4	2.4	19.2	9.6
AD	Quantity	4	0	1	1	11	6
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	38.4	0	2.4	2.4	26.4	14.4

Table 10. BLOS/LOS requirements for surface combatant ships.

Ship Class	Characteristics	BLOS/LOS (Kbps)					
		UHF WSC-3 RX/TX	UHF URC-93 RX/TX	VHF GRC RX	VHF GRT/R RX/TX	HF/MF/ LF RX	HF TX
Aircraft Carrier (CV)	Quantity	33	2	0	1	26	14
	Unit rate	9.6	2.4	0	2.4	2.4	2.4
	Aggregate	316.8	4.8	0	2.4	62.4	33.6
Cruiser (CG)	Quantity	16	1	2	1	13	4
	Unit rate	9.6	2.4	2.4	2.4	2.4	2.4
	Aggregate	153.6	2.4	4.8	2.4	31.2	9.6
Dest-royer (DD)	Quantity	9	1	1	0	16	0
	Unit rate	9.6	2.4	2.4	0	2.4	0
	Aggregate	86.4	2.4	2.4	0	14.4	0
Frigate (FFG)	Quantity	8	0	2	1	10	4
	Unit rate	9.6	0	2.4	2.4	2.4	2.4
	Aggregate	76.8	0	4.8	2.4	24	9.6

Table 11. SATCOM requirements for amphibious ships.

Ship Class	Characteristics	SATCOM (Kbps)			
		UHF WSC-3 RX/TX	UHF SSR-1A RX	SHF WSC-6 RX/TX	EHF USC-38 RX/TX
LHA	Quantity	6	1	1	2
	Unit rate	9.6	1.2	544	10.2
	Aggregate	57.6	1.2	544	20.4
LPD	Quantity	1	1	0	0
	Unit rate	9.6	1.2	0	0
	Aggregate	9.6	1.2	0	0
LST	Quantity	1	1	0	0
	Unit rate	9.6	1.2	0	0
	Aggregate	9.6	1.2	0	0
LSD	Quantity	2	1	0	0
	Unit rate	9.6	1.2	0	0
	Aggregate	19.2	1.2	0	0

Table 12. SATCOM requirements for auxiliary ships.

Ship Class	Characteristics	SATCOM (Kbps) UHF WSC-3 RX/TX	UHF SSR-1A RX	SHF WSC-6 RX/TX	EHF USC-38 RX/TX
AOE	Quantity	2	1	0	0
	Unit Rate	9.6	1.2	0	0
	Aggregate	19.2	1.2	0	0
AOR	Quantity	1	1	0	0
	Unit rate	9.6	1.2	0	0
	Aggregate	9.6	1.2	0	0
AD	Quantity	2	1	0	0
	Unit rate	9.6	1.2	0	0
	Aggregate	19.2	1.2	0	0

Table 13. SATCOM requirements for surface combatant ships.

Ship Class	Characteristics	SATCOM (Kbps) UHF WSC-3 RX/TX	UHF SSR-1A RX	SHF WSC-6 RX/TX	EHF USC-38 RX/TX
Aircraft Carrier CV	Quantity	8	1	1	2
	Unit Rate	9.6	1.2	544	10.2
	Aggregate	76.8	1.2	544	20.4
Cruiser CG	Quantity	5	1	1	1
	Unit rate	9.6	1.2	544	10.2
	Aggregate	48	1.2	544	10.2
Dest-royer DD 963	Quantity	5	1	0	1
	Unit rate	9.6	1.2	0	10.2
	Aggregate	48	1.2	0	10.2
Frigate FFG	Quantity	2	1	0	1
	Unit rate	9.6	1.2	0	10.2
	Aggregate	19.2	1.2	0	10.2

As just described in tables 8 through 13, most of the Navy's external electromagnetic communications are conducted in the radio frequency (RF) portion of the spectrum between 2 MHz and 8.4 GHz. This range of frequencies includes all HF, VHF, and UHF bands, and part of the SHF RF band.

In the past, different radios were needed to operate in the different RF bands. Specialized hardware was required in each radio to implement the waveform types and communications protocols that were specific to a particular radio. This situation is changing. The U.S. Navy is replacing many of its older radios with a single radio—the Digital Modular Radio (DMR). Each DMR has four RF channels that can be programmed to operate in any frequency range from 100 kHz to 2 GHz. The old, radio-specific analog hardware is replaced in the DMR by common, software-controlled digital circuitry. Note, however, that besides the DMR, other components in the RF channel, such as power amplifiers, multicouplers, and especially antennas, are still frequency-band specific.

U.S. Navy HF communications cover the 2- to 30-MHz frequency range. HF is principally used for long-range communications through the HF "skywave." HF communications provide an alterna-

tive or back-up to long-range SATCOM. Of course, because of its lower frequency, HF has lower communications channel capacity than higher frequency SATCOM. The HF "groundwave" can be used for LOS communications within a force, although LOS communications are usually conducted at higher frequencies. Depending on a particular ship's class, from zero to five RF channels will be used for HF communications.

Most of the Navy's LOS communications are conducted in the 30- to 450-MHz (VHF band and lower part of the UHF band) frequency range. Most VHF LOS communication is by the Single-Channel Ground and Airborne Radio System (SINCGARS), which operates between 30 and 88 MHz. SINCGARS uses a frequency-hopping protocol to reduce its vulnerability to jamming. The U.S. Navy also retains some legacy systems that are used in amphibious and land–mobile operations. These systems operate in the VHF band from 116 to 162 MHz. On a given U.S. Navy ship, depending on its class, from 1 to 24 RF channels will be assigned to VHF communications. Most VHF channels—as many as 20—will be used for SINCGARS.

U.S. Navy UHF LOS communications operate in the 225- to 450-MHz frequency range and carry the bulk of the Navy's tactical communications. An individual ship will have from 4 to 38 UHF radio channels. Typically, from one to four of these UHF channels will be assigned to HAVEQUICK, which has frequency-hopping capability.

The Fleet Satellite Communications System (FLTSATCOM) and the Defense Satellite Communications System (DSCS) provide long-range satellite communications to the U.S. Navy. FLTSATCOM is available on nearly all U.S. Navy ships. It is a wideband, high data rate system that operates within the U.S. Navy UHF band from 240 to 318 MHz.

DSCS operates in the SHF band from 7.25 to 8.4 GHz. The Navy uses the AN/WSC-6 radio in this frequency range. DSCS may be used for very high volume communications but because of the size and weight of the paraboic-reflector antenna (AS-3399) used with the system, DSCS is usually available only on larger U.S. Navy ships. A pair of antennas is also required to provide full hemispherical coverage for satellite access.

Another strategy is to use the Ku band. The Ku band covers the 12.5- to 18-GHz frequency range. INTELSAT currently uses portions of the Ku band for commercial traffic. USS *JOHN C. STENNIS* (CVN 74) currently subscribes to this service. The U.S. Navy continues to develop Ku band antennas composed of phased array elements. The benefit to the telemedicine community is that a phased array antenna system accommodates multidirectional telecommunications that can occur at once. Using the Ku band for telemedicine applications should be considered a significant supplement to the RF spectrum. SATCOM and LOS communications can be satisfied within a common part of the spectrum. Figure 9 shows a possible scenario for Ku-band communication.

A Common Data Link (CDL) requirement is emerging today. CDL will enable elements such as relay satellites, relay aircraft, and Unmanned Aerial Vehicles (UAVs) to connect battle groups in different theaters, or to connect a battle group with shore operations.

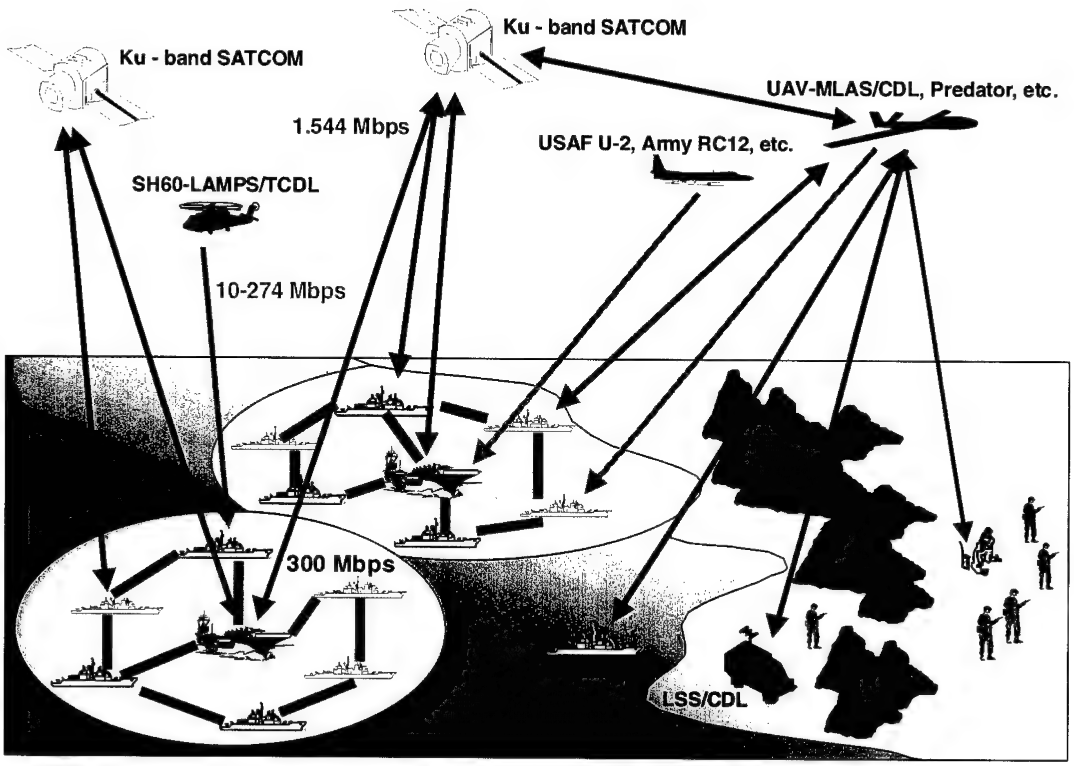

Figure 9. Implementing the Ku band to work for telemedicine applications will help relieve bottlenecks and further mitigate shutdown of telemedicine communications that are pre-empted by combat systems communications.

RESOURCE MANAGEMENT

One of the main problems facing the U.S. Navy telemedicine community is the competition for bandwidth among its various systems. During times of threat, the combat systems will consume all available bandwidth. This is a complex problem with no current solution. One strategy network operations planners can implement is to provide infrastructure that uses every opportunity to update the information in local databases as a temporary stand-alone system aboard ship or at a shore station. When combat systems take over the available bandwidth, medical personnel will still have recent information to fulfill the basic duties.

Another strategy is to prioritize the classes of telemedicine operations to be performed when bandwidth becomes available. For example, after threat conditions decrease, bring the telemedicine systems back "online" in layers. Stage one would be to transmit and receive medical logistics. Stage two would be to update the databases aboard all ships and shore stations. Stage three would then allow real-time telemedicine access. This is a problem whose solution will need high-level consideration and approval for implementation. The idea behind these suggested strategies is to receive and update changes in information to baseline data during times of otherwise low-bandwidth usage.

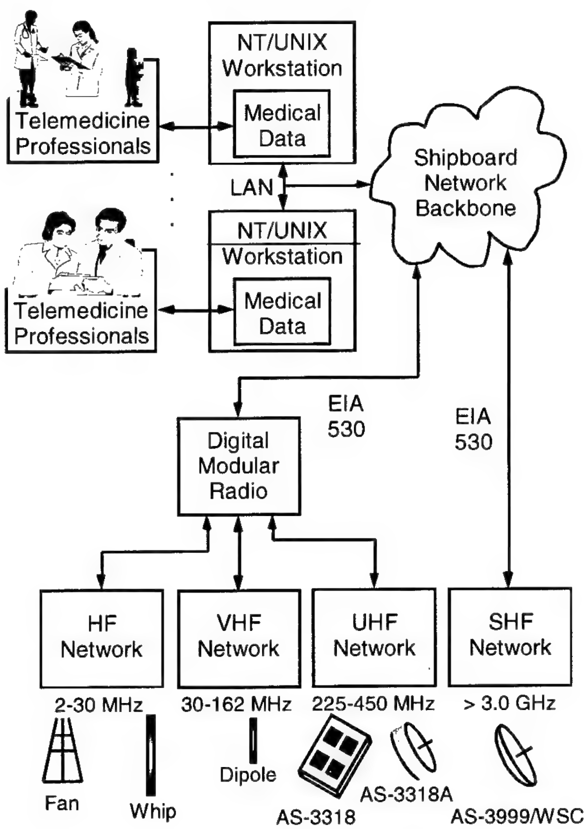

Figure 10. The significant choke point in communication among elements of battle groups is the bandwidth available to all the ship radios.

Normally, medical personnel will not get into the details of how information is exchanged. A typical telemedicine interface looks just like the Internet to user personnel; the information really travels through various communication channels. Many networks and protocols are part of hybrid network systems. Figure 10 shows a typical shipboard architecture. Information about the future of U.S. Navy communications systems is of paramount importance to the telemedicine community so that it can efficiently evolve to meet the demands placed on it.

For ships underway, communication can be classified into internal and external categories. Internal communications include Non-classified Internet Protocol Router Network (NIPRNET), Secret Internet Protocol Router Network (SIPRNET), telephones, and video conferencing. ATM and Internet Protocol (IP) and User Datagram Protocol (UDP) networks and other hybrids of standards are also aboard ships. Network engineers who have monitored internal traffic are in general agreement that the communications "choke point" is always encountered at the interface where off-ship communication occurs.

TELEMEDICINE SERVICES

Previous sections summarized the U.S. Navy communication systems and their current bandwidth capacities. This section describes how telemedicine services can be provided over existing and future U.S. Navy telecommunication systems. Assuming that a network and computer infrastructure exists between ships and shore facilities, a communications path can be established. MTFs aboard ships can then be linked to shore facilities. Figure 8 shows a possible telemedicine architecture between U.S. Navy ships and several shore facilities. In this example, communication facilities at SSC San Diego, LOS or SATCOM, can link any ship to terrestrial networks connected to the Naval Medical Center San Diego, the Navy Health Research Facility (NHRC), the National Institute of Health (NIH), etc. At SSC San Diego, telemedicine data will be converted to a terrestrial network such as the Internet or point-to-point T1 links.

As part of the U.S. Navy telemedicine architecture, the following equipment is required:

- **Remote Viewing Workstations.** These workstations will be used by IDCs to acquire images, microspecimens, vital signs, and patient information. The workstations will have multimedia interfaces and will operate in a Windows NT® environment.
- **Local Viewing Workstation.** These workstations will be used by medical staff at medical centers such as the Navy Medical Center San Diego to provide medical consultation services in the interactive remote telemedical consultation. The workstations will work in store and forward mode and will also have multimedia interfaces and operate in the Windows NT® environment.
- **Database Archive System.** This system will consist of UNIX-based systems used for multimedia storage and archiving of medical records, images, voice, video, text, etc.
- **Portable Workstation.** These workstations will be used in space-limited ships such as submarines, frigates, and destroyers. Portable workstations will be more limited than the other workstations, but will still include image viewing, vital signs, and patient information.

COMMUNICATIONS PROTOCOLS

Different protocols are used for the transmission of information during a telemedicine session. This section summarizes the protocols used at the Transport, Network, and Data Link layers used by U.S. Navy communications systems.

Data Link Protocols

Data link protocols include the following:

- **High Level Data Link Control (HDLC).** HDLC was published as ISO 3309, 4335, and 7809 and used in products that support X.25, ISDN, and Ethernet LLC.
- **Link Access Protocol-B (LAP-B).** LAP-B was published by ITU-T (as X.75) and used to provide a reliable frame transfer mechanism through a selective reject ARQ that is useful for maximizing efficiency in a long delay or high data rate applications.
- **Hand-Off Assigned Multiple Access (HAMA).** HAMA was first implemented in the Unified Networking Technology-Advanced Technology Demonstration (UNT-ATD). It is a MAC sublayer channel access protocol designed for the HF environment.

- **Demand Assignment Multiple Access (DAMA).** Standard MAC protocol for UHF SATCOM. Versions are being developed for SHF SATCOM. This protocol does not provide functions like ARQ but can be used with an appropriate link control protocol such as HDLC or LAP-B.

- **MCA Multichannel Architecture.** This architecture was designed for HF- and DAMA-arbitrated UHF SATCOM resources. The MCA Multichannel Architecture provides single TX and multiple RX frequencies, integrates a datagram and streamed virtual circuit channel on a common physical channel, provides quality of service (QOS), uses compressed low data rate digital voice and header compression for TCP packets to conserve bandwidth, and performs automatic configuration to guarantee connectivity.

- **Navy EHF Communications Controller (NECC).** NECC implements the CSS architecture that uses EHF satellite resources as the bearer service. NECC sites use the NECC Subnet Access Control (SAC) protocol to access an EHF terminal (AN/USC-38) through a link encryption unit (KG-84A) whose functionality depends on the type of ship. It uses convolutional encoding, bit interleaving, and frequency hopping. SAC functions include multiple access, datagram queuing, and net management.

- **Asynchronous Transfer Mode Application Adaptation Layer (ATMALL).** ATMALL allows the asynchronous multiplexing of different types and classes of traffic onto a single high-speed network.

- **Point-to-Point Protocol (PPP).** Internet standard (RFC 1661, 1547). PPP is suited for multiplexing multiprotocol datagrams over a point-to-point link. It encapsulates multiprotocol network layer datagrams for transfer over a full-duplex synchronous or asynchronous link using HDLC-type framing.

- **Serial Link Internet Protocol (SLIP).** SLIP was developed for framing IP diagrams over a serial line. Its only function is framing.

Network and Transport Protocols

Network and Transport Protocols include the following:

- **Transmission Control Protocol and Internet Protocol (TCP/IP).** DoD developed TCP/IP. IP provides a variable length datagram service. IP gateways are usually connected to one or more Local-Area Networks (LANs), Ethernet, and one or more Wide-Area Networks (WANs) that directly link them to other IP gateways. TCP uses the IP as a service to provide a reliable connection between source and destination. Lost datagrams can be detected by checksums and sequence numbers. TCP/IP can transfer all multimedia information in the telemedicine services except the video objects.

- **User Datagram Protocol (UDP).** UDP uses the IP protocol to provide a delivery service to the application layer but does not provide any mechanisms to improve the underlying IP service. It can transfer telemedicine video and audio packets over a switched or packet-switched network because it does not require an acknowledge for each packet transfer.

ISO Protocols

The following protocols have been identified as having potential capability in the IC4I environment. Many or all of these protocols may not be operational in U.S. Navy communications systems.

- **ISO 8073 (ITU-T X.224).** This protocol provides a connection mode transport service. Class 4 (TP4) of this protocol supports error correction and recovery. It is the best choice.
- **ISO 8602.** This protocol provides connectionless mode transport. It does not provide any mechanisms to improve the underlying network service. Service is unreliable. Its primary value is the inclusion of port numbers that allow multiple applications to share the transport service.
- **ISO 8878.** This protocol provides a connection oriented network service. It includes establishment, data transfer, and connection release. It provides functions that are traditionally provided at the transport layer.
- **ISO 8473.** This protocol provides connectionless mode network service. Best effort delivery is similar to IP and relies on higher level protocols to perform sequence control, flow control, and error recovery.
- **ISO protocol Stacks.** This protocol combines different protocols. ISO fields can be tailored for the delivery of telemedicine objects.
- **ATM and Application Adaptation Layer (AAL) Protocols.** Each ATM has its own AAL. AAL enhances the adaptation of services provided by the ATM layer to the user requirements of the higher layer. The combination of ATM and AAL protocols for the transfer of telemedicne objects has been demonstrated by several researchers.

INTEGRATED MULTIMEDIA TELEMEDICINE SERVICES

A telemedicine remote consultation and diagnosis (RCD) service requires four different objects to be transferred: static images, image annotation, real-time voice, and patient information. An RCD requires about 200 Kbps for a single session. A single U.S. Navy communications resource cannot sustain the bandwidth required for an RCD session. Other resources must be used. In a typical RCD session, image annotation and voice objects might be connected to a UHF LOS communications system. Static image transfer might be connected to a SATCOM communications system. Figure 11 shows the transfer of integrated multimedia telemedicine services through the CSS.

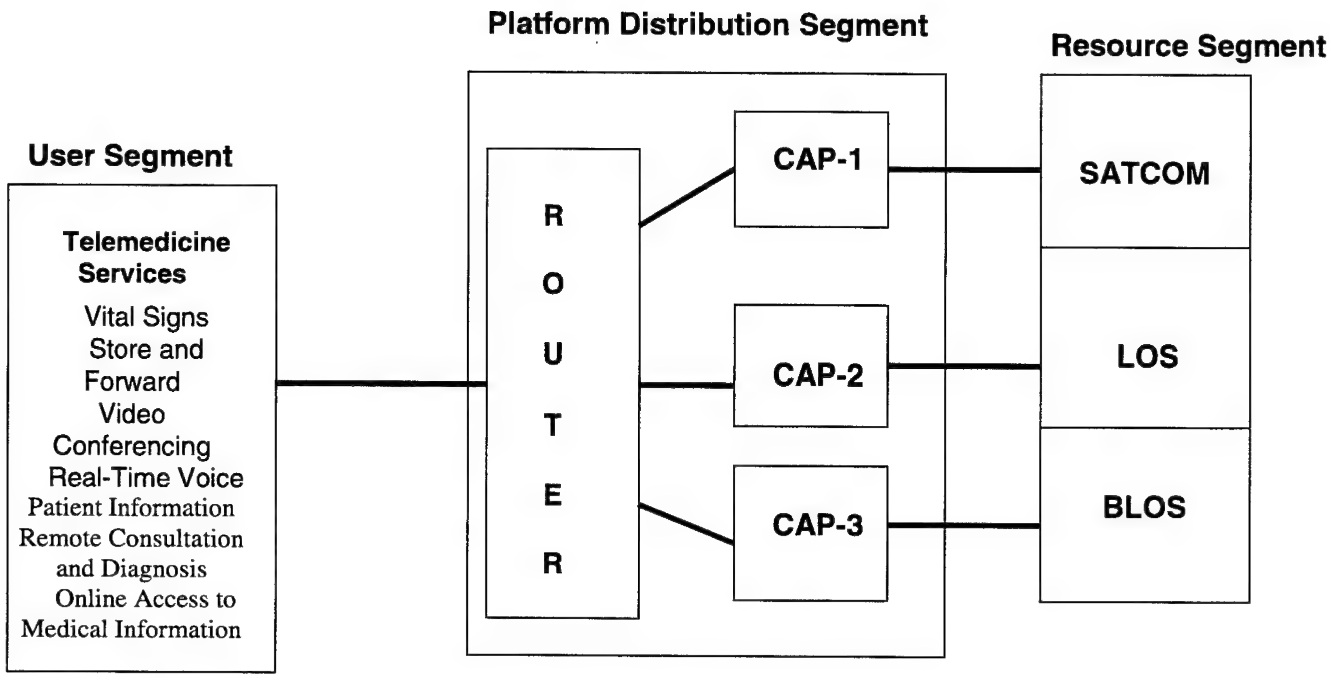

Figure 11. Transfer of integrated multimedia services through the CSS structure.

This architecture defines a user segment system where the telemedicine system transfers the telemedicine objects to the Platform Distribution Segment that routes the information to an appropriate Channel Access Protocol (CAP) unit. Each CAP forwards the information to the Resource Segment communications system that can sustain the required bandwidth for that specific object or group of objects.

Tables 14 through 19 show an assessment of the capabilities of each ship type by class: aircraft carrier (CV), cruiser (CG), destroyer (DD), frigate (FFG), amphibious (LA), and auxiliary (AOE). The bandwidth capability of each ship may be categorized as one of two types: Low Data Rate Resources or High Data Rate Resources. Each table entry is represented by either a letter, G, a letter, M, or a letter, P. These letters have been assigned the following descriptions:

- **Good (G).** The communications system can handle the required bandwidth for telemedicine application or service.
- **Medium (M).** The communications system has a limited capacity to handle the required bandwidth.
- **Poor (P).** The system cannot handle the required bandwidth.

Table 14. User services versus communication resources for aircraft carrier (CV).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	G	G	G	G	TBD	G	G	G	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	G	G	P	TBD	P	G	G	M
PCD	P	P	P	P	TBD	P	M	M	M
Patient Info.	G	G	G	G	TBD	G	G	G	G
On-line Med. Info.	P	G	P	P	TBD	P	G	G	G

Table 15. User services versus communication resources for cruiser (CG).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	G	G	G	M	TBD	M	G	G	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	G	P	P	TBD	P	G	G	M
PCD	P	P	P	P	TBD	P	M	M	M
Patient Info.	G	G	G	G	TBD	G	G	G	G
Online Med. Info.	P	G	P	P	TBD	P	G	G	G

Table 16. User services versus communication resources for destroyer (DD).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	M	G	G	P	TBD	P	P	P	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	P	P	P	TBD	P	P	P	M
PCD	P	P	P	P	TBD	P	P	P	M
Patient Info.	G	G	G	G	TBD	G	P	P	G
Online Med. Info.	P	P	P	P	TBD	P	P	P	G

Table 17. User services versus communication resources for frigate (FFG).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	G	G	G	P	TBD	P	P	P	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	P	P	P	TBD	P	P	P	M
PCD	P	P	P	P	TBD	P	P	P	M
Patient Info.	G	G	G	G	TBD	G	P	P	G
Online Med. Info.	P	P	P	P	TBD	P	P	P	G

Table 18. User services versus communication resources for amphibious ship (LHA).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	G	P	G	G	TBD	G	G	G	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	P	P	P	TBD	P	G	G	M
PCD	P	P	P	P	TBD	P	M	M	M
Patient Info.	G	P	G	G	TBD	G	G	G	G
Online Med. Info.	P	P	P	P	TBD	P	G	G	G

Table 19. User services services communication resources for auxiliary ship (AOE).

Services and Operations	Low Data Rate Resources				High Data Rate Resources				
	HF	UHF/ VHF LOS	UHF SATCOM	EHF LDR SATCOM	IN-MAR SAT	EHF MDR SATCOM	X-band SHF SATCOM	Ku SHF SATCOM	Broad-band Terres-trial
Vital Sign	P	G	P	P	TBD	P	P	P	G
Video Conf.	P	P	P	P	TBD	P	P	P	P
Store/ Forward Static Image	P	P	P	P	TBD	P	P	P	G
Real-Time Voice	P	G	P	P	TBD	P	P	P	M
PCD	P	P	P	P	TBD	P	P	P	M
Patient Info.	G	G	G	G	TBD	G	G	G	G
Online Med. Info.	P	P	P	P	TBD	P	P	P	G

TELEMEDICINE SERVICES ON THE INTERNET

Communication and information technologies have grown impressively during the last few decades, with millions of computers, cell phones, fax machines, etc. supporting daily activities. The medical community has also taken advantage of new technologies, incorporating more sophisticated systems in the diagnoses and treatment of patients and in post-treatment practices. One of the most challenging aspects of modern medicine is storing and accessing large amounts of medical information. The Internet age has helped tremendously because it allows data banks at different sites and provides a relatively quick link between them.

In the near future, medical staff will access all relevant information about a patient from the Internet. Information banks may contain medical records, x-rays, audiotapes, still images, and video streams from various video and imaging devices. This information may be in a menu or web-browser format that is readily available for the authorized user. Very high security controls must prevent unauthorized access to personal medical records. Sophisticated techniques such as smart cards with fingerprint or iris recognition may be used as an access code.

The Internet may also provide real-time patient-to-doctor and doctor-to-doctor/hospital communication or video conferences that would allow rapid exchange of medical information. Basic Internet services such as e-mail also provide real-time communication with some limitations on the format and type of information exchanged. This type of communication has almost unlimited possibilities including linkage to any geographical area and access to any medical information bank, creating a virtual hospital. Figure 12 shows a possible Internet configuration where health care providers access data banks with medical records and history, and access to laboratories, test results, and virtual hospitals and other research facilities.

The Virtual Naval Hospital™ (VNH) (University of Iowa, 2001) is a digital science library whose mission statement reads "The NVH is designed to deliver information to providers and patients at the point-of-care in order to help providers take better care of their patients and help patients live healthier lives." The NVH provides convenient and prompt access to valuable medical information essential to the medical staff onboard a ship to deliver high-quality medical care for the warfighter. The NVH helps in disease diagnosis, decision support, treatment, follow-up care, and educational programs that can be integrated with the U.S. Navy's and DoD's current and future telemedicine programs. The NVH removes the isolation, time and distance factors between the patient and the medical care provider, bringing medical knowledge to the point-of-care, allowing for better medical care to be delivered to the warfighter, and improving mission readiness.

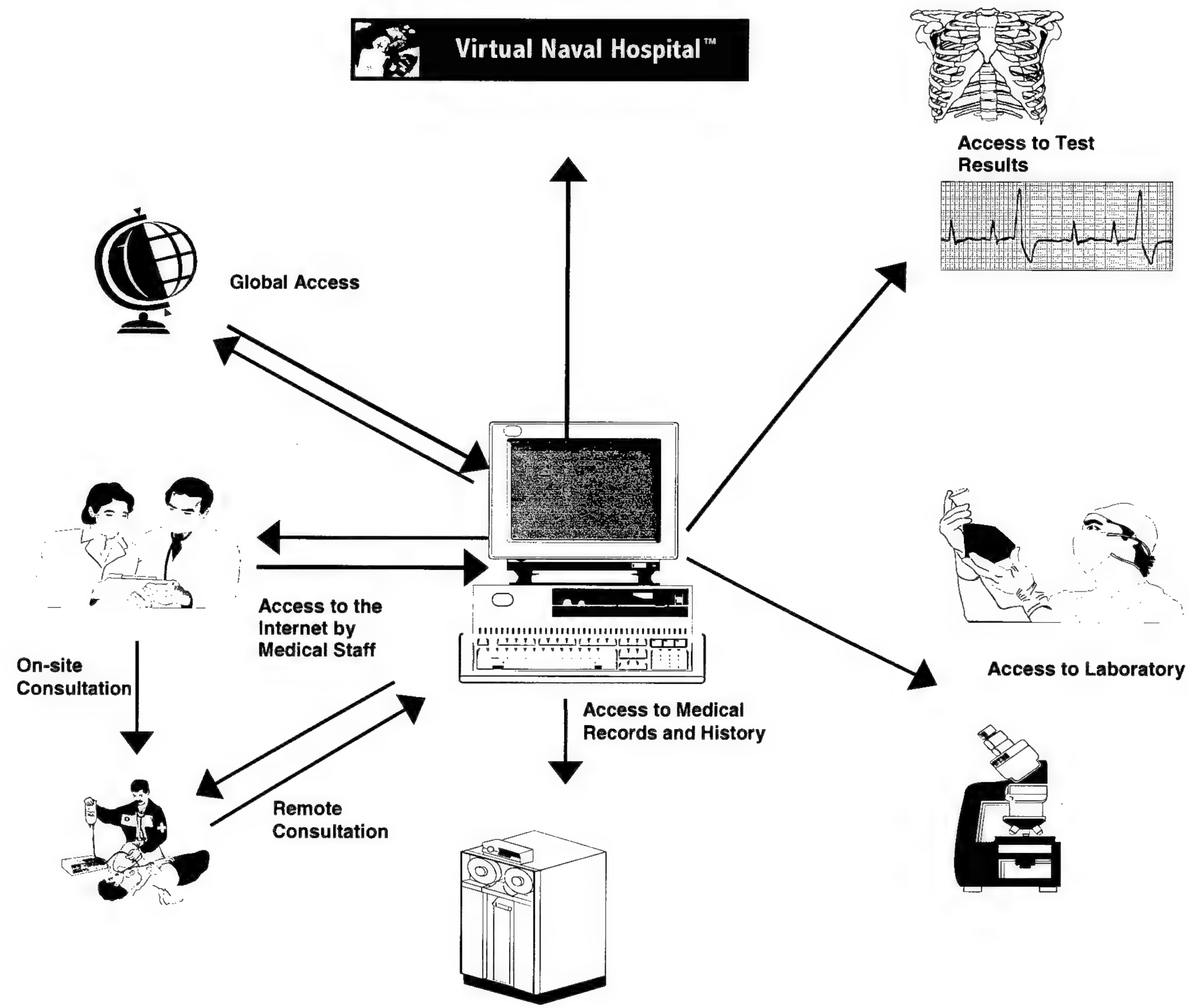

Figure 12. Internet telemedicine applications.

Another effort is the Global Health Network (GHNet) (University of Pittsburgh, 1998), which will to provide a gateway for global public health information. GHNet was formed by a group of experts in telecommunications and health. The participating agencies share a developing health information architecture and include the NASA, the World Health Organization, the Pan-American Health Organization, the World Bank, and the U.S. Agency for International Development. GHNet's goals are to serve as a liaison among the agencies, to foster global health tele-prevention and tele-education, and to develop more specialized programs

These new efforts to use Internet services in telemedicine applications have prompted the National Library of Medicine (NLM) to request a study by the Computer Science and Telecommunications Board of the National Research Council (NRC) that would "evaluate the technical capabilities demanded by health applications on the Internet." The study examined applications of the Internet in six areas: consumer health, clinical care, health care financing and administration, public health, professional education, and biomedical research. The results of the study (Computer Science and Telecommunications Board of the NRC, 2000), summarized in this section, identify the technical capabilities that telemedicine applications demand of the supporting networks and other communications equipment. Specific telemedicine applications are envisioned in which text, voice, video, and graphic files are transferred through the Internet, medical and laboratory equipment are remotely controlled, vast searches of information are performed in seconds, and real-time collaboration among medical staff allows for prompt medical decisions. The advantages of the Internet are as follows:

- Access to health records and online consultation
- Identification of unconscious patients and access to patient's records
- Delivery of medical care instructions
- Real-time video connections from anywhere; interfacing with medical devices
- Consultation among specialists by manipulating shared 3-D images and simulating surgical procedures
- Allows Health Maintenance Organizations (HMOs) to provide instantaneous approval
- Allows public health officials quick access to laboratory results such as water contamination issues
- Helps medical staff by providing quick access to clinical information regarding medical cases never encountered before
- Helps in the advancement of medical research by allowing remote manipulation of data and equipment

TECHNICAL CHALLENGES

Current research in communications and networking technologies promises to greatly enhance the Internet capabilities. The Internet still faces monumental challenges before it can implement the proper protocols for QOS that can guarantee users the availability of bandwidth and latency across the network. These demands are even greater for the transmission and manipulation of medical information, and the consequences can be much more serious when QOS is not met. The technical

challenges and limiting technical factors in clinical care applications are as follows:

- Real-Time Video Transmission (remote medical consultation between patient and medical staff or among medical staff)
- Static File Transfer (transfer of medical records such as X-ray, EKG, MRI, CT scans, ECG)
- Remote Control (remote and virtual surgery)
- Real-Time Collaboration (consultation among medical care providers such as planning a surgery, etc.)
- Information Search and Retrieval (search of professional medical literature, practice guidelines, etc.)
- Primary Technical Challenges (access to sustained bandwidth, low latency for remote consultation and collaboration); security of medical records, network reliability, ubiquity of access for care providers

Medical care providers cannot perform critical functions unless they are assured that the information will be transmitted quickly, accurately, and under the strictest confidentiality. Providers and patients must obtain sustained access to sufficient bandwidth services for their specific application such as video telemedicine. Bandwidth and latency may be critical factors in medical emergencies.

Medical images such as X-rays, CT, and magnetic resonance imaging (MRI) comprise hundreds of megabites of information that need to be transmitted and sometimes compared with each other before a diagnosis or treatment. Medical information puts a tremendous demand on the capabilities of digital networks and still requires that this information be transmitted from point A to point B in seconds. Latencies for information transmitted across the Unites States can vary from 100 milliseconds to about a second. This variation may be acceptable for some applications such as e-mail, but it can render video-conferencing applications useless. Packet loss across the Internet can vary from 1 to 10 percent, which can lead to degraded transmission quality. Lost packets must be retransmitted, which increases latency. Future Internet technologies must solve these problems if telemedicine applications are to be fully functional across the Internet.

ANALYSIS OF POSSIBLE SOLUTIONS

One possible solution is to increase the bandwidth of the network backbones. Current speeds of backbones range from 600 Mbps to 2.5 Gbps. Wavelength Division Multiplexing (WDM), with each wavelength supporting up to 10 Gbps, is being used to test optical fiber links for their capacity to carry up to a 100 wavelengths. This capacity can be compared with carrying more than 15 million phone calls simultaneously on a single fiber. Equipment cost has been a limiting factor in the advancement of this technology. The equipment consists of SONET termination equipment and the specific routers and switching devices needed to transmit packets between points of presence (POPs). Available commercial routers can support at least 16 OC-48 (2.5 Gbps) interfaces. Routers with 24 times this capacity are currently under development. Even with such an increase in bandwidth, congestion may still be a problem because the demand for bandwidth is increasing at a faster rate than its availability. As digital imaging technology evolves, the resolution increases and, hence, the demand for bandwidth. A typical medical image file will probably contain several gigabytes in the near future, compared with the current value of 250 MB.

Increasing bandwidth does not always lead to better QOS. Internet TCPs may limit the capability of the Internet Service Providers (ISPs) to provide better services by simply increasing bandwidth because TCPs determine the bandwidth of the slowest, most congested link for a given path and maximizes bandwidth use at that point. Links are just as fast as the slowest link in the path. Adding more bandwidth transfers the congestion to a different point. Unless all links are upgraded to the required bandwidth, delay-sensitive medical applications will still suffer from time lags.

The Internet Engineering Task Force (IETI) is developing two mechanisms to provide QOS across the Internet: differential services (diff-serv) and integrated services (int-serv). Differential services allow an ISP to sign up for a given rate (i.e., 128 kbps) and expect better service than just best effort, which depends on traffic load and bandwidth availability. ISPs will assign enough bandwidth to ensure a very low probability of a packet loss, maybe as low as 0.0001% or one in a million. This mechanism provides customers with assurance that information will get to its destination in a complete and prompt manner.

Integrated service (Braden et al., 1997) provides quantifiable QOS guarantees for specific data transmissions from point A to point B. As an example, an IP could guarantee that during a video teleconference, point B will receive a minimum of 128 Kbps throughput and a maximum of 0.1 seconds latency. To achieve this, integrated service includes a signaling mechanism called resource reservation protocol (RSVP) that allows applications to request specific QOS guarantees and, as long as resources are available, the request will be accepted.

A combination of these two mechanisms will probably be adopted as an optimized way to transmit information across the Internet. Another approach uses virtual overlay networks (VONs) to support the creation of independent networks to link multiple participants and offer different levels of QOS.[†] This approach requires much more sophisticated routers that would partition packet flows according to flow identifiers and would allocate a predetermined portion of their capabilities to a specific flow. All adaptive processes described in this section would alleviate some of the congestion and delay problems experienced by every Internet user.

In addition to the QOS mechanisms, a broadcast model of the Internet is currently being optimized for deployment. These broadcast systems will use available bandwidth more efficiently to simultaneously distribute information from a single user to many recipients. System applications will include continuing medical education with real-time transmissions, teleconsultations among geographically dispersed public officials and medical staff during medical emergencies, public health hazards, bioterrorist attacks, etc. Health care applications may involve many multicast groups attempting to transmit information from a dynamic member attempting to link physicians, hospitals, databases, etc. The dynamic member could be a ship constantly changing position, speed, and orientation. More health care applications must be considered to ensure that future multicast systems fully support telemedicine.

[†] K. P. Birman. 1999. "The Next Generation Internet: Unsafe at Any Speed?" Department of Computer Science Technical Report," Draft of October 20, Cornell University, Ithaca, NY.

REQUIREMENTS

FUNCTIONAL REQUIREMENTS

SPAWAR Systems Command, under guidance from Commander in Chief, U.S. Pacific Fleet[‡], and Commander in Chief, U.S. Atlantic Fleet[†], assembled a minimum set of essential U.S. Navy and Marine Corps requirements as part of the Theater Medical Information Program-Maritime (TMIP-M). The section summarizes the minimum set of requirements.

Medical Administration

Patient demographic data and basic health information must be stored and tracked. When patients move to other locations, medical administrators must be able to recall medical records. Basic record-keeping about each patient is necessary to recall information about allergies, immunization history and information about adverse reactions, vision and dental records, sexually transmitted diseases, and duty status. Administers must be able to recall and update the relevant information and port the information to where it is needed.

Radiation Health

All periods of radiation monitoring for exposure must be documented and tracked. The periodic and cumulative lifetime exposure must be measured and tracked for each patient.

Occupational and/or Environmental Health

All occupational health elements must be documented as required by DoD and Department of the Navy (DoN) directives. Typical areas of concern include fulfilling reporting requirementss and documenting and tracking heat stress, water testing, and pest control programs.

Medical Encounters

All health care encounters must be documented. Documentation includes documenting emergency treatment, routine sick call follow-ups, producing consultation requests, and facilitating the storage and recall ability for pre- and post-deployment surveillance questionnaires. Fulfill reporting requirements, including controlled substance verification reports. Reports for accident or injury should be automatically generated.

Supply

A system is required to track the procurement, storage and expenditure of medical materials within medical department spaces and storerooms. Inventories must be tracked by item, location, expiration date, and/or lot number. Medicinal materials must also be tracked. Procurements must also be

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[‡] Letter 5200 Ser N02M/061, 18 March 1998, Statement of Fleet Requirements for Medical Information Management (IM) Information Technology (IT).

[† †] Letter 2300 Ser N01/1092, 25 February 1998, Statement of Fleet Requirements for Medical Information Management (IM) Information Technology (IT).

tracked. The system must interface with standard U.S. Navy supply programs and generate standard reports, forms, and logs.

TECHNICAL REQUIREMENTS

This section describes the bandwidth requirements for different U.S. Navy telemedicine services. The information presented here is based on years of experience in medical and imaging systems obtained by medical staffs from all disciplines and on actual performance measurements and simulations of telemedicine systems. This information was taken from a 1996 draft report[16] that compiled these findings. The object class and type determine the bandwidth requirements; the object type determines the number of bytes required for each telemedicine scenario; the telemedicne scenario determines the frequency at which information will be transmitted or received. A bandwidth requirement was developed for each telemedicine service. The requirement can then be matched with the bandwidth capability of U.S. Navy communications resources. Table 20 lists the bandwidth requirements for different telemedicine services. These requirements change, depending on delivery time and data structure, but this table provides a good indication of the bandwidth requirements for complete telemedicine services.

Table 20. Definitions of multimedia object classes used in telemedicine applications.

Telemedicine Service	Bandwidth Requirement	Type	Data Structure	Delivery Time (sec)	Bandwidth Required (Kbps)
Vital Sign Transfer	Two Vital Sign object types; the first one is single reading, represented by two bytes each for blood pressure, heart rate, and temperature. If one assumes a minimum packet with 400 bytes, where the two required bytes are embedded, then the required bandwidth is 3200 bps. The second one, an ECG object type, requires 24 Kbps, assuming a maximum of 12 channels (250 bytes per channel).	BP	2 bytes	1	3.2
		HR	2 bytes	1	3.2
		TEM	2 bytes	1	3.2
		ECG	2 Kbps	1	24.0
Static Image (store and forward)	Three different types: Computed Radiography (CR), CT, and X-ray. Because store and forward services do not require immediate transfer, an arbitrary 120-second delivery time has been assigned. No compression. Bandwidth requirement for pathology and dermatology images may vary because they are in color and use 24 bits of color level per pixel.	CR	512 x 512 x 8 bits	120	17.5
		CT	1K x 1K x 8 bits	120	66.7
		X-ray	2K x 2K x 12 bits	120	400.0
Video Conferencing	Two types of transmission methods: digital MPEG video and analog TV video. For digital video, assume a small 320 x 280 x 24 bit-frame and a full-motion rate of 30 frames per second. Then, the required bandwidth for full-motion MPEG video is 45.2 Mbps (70% MPEG conversion for each frame). Additional bandwidth is required for synchronization of the digital video with audio digital packets. Analog video is assumed to use a standard CATV 8-MHz channel.	Digital	320 x 280 x 24-bit MPEG	30 frames/ sec.	45,200
		Analog	N/A	N/A	8-MHz channel
Real-Time Voice	Digital and analog voice transmission. Digital audio transmission requires 64 Kbps for each channel, send and receive. Analog audio requires a 3- to 8-kHz channel.	Digital	N/A	N/A	Two channels at 64 Kbps
		Analog	N/A	N/A	One channel, 3 to 8 kHz

Table 20. Definitions of multimedia object classes used in telemedicine applications. (continued)

Telemedicine Service	Bandwidth Requirement	Type	Data Structure	Delivery Time (sec)	Bandwidth Required (Kbps)
Patient Medical Information	Text. Assume that patient medical information can be included in 4 Kbytes and transmitted within 30 seconds; total bandwidth required is then 1.1 Kbps.	Text	4 Kbytes	30 sec	1.1
Online Medical Information	Connection to the Internet and the World Wide Web. Object type is hypertext, which may include text, audio, static images, and digital video sequences. Assume a 1-MB transfer of hypertext information during a 30 seconds. Total bandwidth required is 267 Kbps.	Hyper-text	1 MB	30 sec	267.0
Image Annotation and Pointing	Annotations can be included in 400 bytes but delivery time has to be around 200 milliseconds.	Real-Time Data	400 bytes	200 msec	16.0
Remote Consultation and Diagnosis Session	Three types of objects transferred simultaneously: 8 Mbytes of static image (66.7 Kbps), two digital voice channels (128 Kbps), and two channels of image annotation commands (3.2 Kbps). The required bandwidth is then 197.9 Kbps. This requirement increases significantly when MPEG video is added to this telemedicine scenario.	Multi-media	Image: 8 Mbytes Voice: 128 Kbytes Annotation: 800 bytes	120 sec 1 sec 1 sec	197.9

ENHANCEMENTS

NEAR-TERM ENHANCEMENTS

Emerging collaborative reliable multicast (CRM) technology can affect telemedicine aboard U.S. Navy ships. One problem is that when a high threat occurs, combat systems usurp the available bandwidth. This is precisely the time when casualties occur and when important parts of the medical system are most needed. Implementing CRM would provide the following near-term gains to the U.S. Navy telemedicine community:

- The CRM Framework is a set of three forwarding services and two reliable multicast (RM) protocols, CRMv1 and CRMv2
- CRMv1 and CRMv2 use distributed error recovery (DER)
  - They use bandwidth efficiently
  - The data source is NOT a single point of failure—error recovery can occur in DER as long as each datagram has been received by one or more receivers
- DER robustness is very appropriate for tactical networks where node and link failures are much more likely to occur at the most critical times
- CRMv1 works in networks that support the current standard for IP multicast
- CRMv2 uses minor enhancements to IP multicast to achieve much higher scalability and lower latencies than current multicast technology provides
- The CRM Forwarding Services (CFS) interconnect islands of multicast capability that are separated by problem regions such as:
  - Networks that lack multicast capability
  - Asynchronous networks
  - Unidirectional networks
- The CRM protocols and the CFS support near- and long-term deployment of robust reliable multicast for military networks

Many pieces of telemedicine have been implemented as evaluations and demonstrations aboard *CORONADO* during Rim of the Pacific (RIMPAC) Humanitarian Response Exercises 2000. Strong Angel was conducted June 2000 as part of RIMPAC 2000. Strong Angel conducted two experiments. Experiment 1 included one-way information translation and a two-way interactive information translation component, an interactive paging system, and a demonstration of alternative power concepts. Experiment 2 included distributed medical communications, civil–military interactions and communications, and a humanitarian information management element.

Advanced Wireless Networks (DAWN) Demonstration

Transitioning technology from the Demonstration of Advanced Wireless Networks (DAWN) project may provide another near-term benefit for the telemedicine community. Elements of DAWN are implemented as an integrated system of systems. One concept of operations puts an unskilled technician on a beach just stormed by LCAC forces. DAWN allows access to experts in healthcare

delivery for technicians and surviving field personnel in hostile areas. DAWN enhances technologies such as CRM with several elements assisting the human interfaces for sending and receiving information. DAWN is also evolving useful input/output (I/O) interfaces for the next enabling step in telemedicine field-deployable robotic medical assistants.

Wearable Computers. DAWN actually demonstrated that lightweight computers are easily wearable and accommodate various instrumentation and inputs and outputs. The telemedicine community can add to this infrastructure by developing its own set of instrument suites.

I/O Enhancements. There are several information interface possibilities:

- **Head-Mounted Display.** Head-mounted displays the size of postage stamps are successfully used as fair resolution video display terminals. Current demonstrations show information such a user position in a terrain map and orientation of user and ground track superimposed onto a terrain map. The displays could also interface with other sensors over the network to display information about the enemy. The telemedicine community could use the same infrastructure to provide field personnel with a display terminal in hostile areas.

- **Remote Video Capture Hardware.** Cameras on field personnel bring information back to experts. They can see what the field person sees.

- **Interfaces with Existing Communications Links.** There are many options that still need exploration. The versatility of today's computer provides many options for connectivity. Situations range from from adding peripheral hardware components to an existing computer to adding access to entire networks of other systems.

Current trends thrusts are toward integration of Modular Robust Technologies. Figure 13 shows a 2-year projection for the integration of these technologies and the services they will provide.

Data Compression

New technologies in data compression have turned mathematical theories into COTS technology that the military should use. JPEG and MPEG have been the standard image and video compression formats for the past 10 years. New wavelet-based algorithms have recently ousted the Direct Cosine Transform (DCT)-based JPEG and MPEG formats. Companies such as Apple, Analog Devices, Microsoft, and Lucent Technologies have already taken advantage of the wavelet algorithm approach, commercializing new compression schemes of their own (Dibert, 2000). For example, Lucent Technologies recently published a report of a new compression scheme that makes 3-D image applications very accessible to lower bandwidth applications. Using wavelet-based algorithms, geometric data can be compressed up to 12 times more efficiently than the newest of the MPEG4 standards (Schroader et al., 2000). The new JPEG format called JPEG2000 is also wavelet-based and promises a fivefold file compression improvement over its original JPEG format while boasting an even higher image quality (Johnson, 1999). The federal Bureau of Investigation (FBI) has even adopted a wavelet-based standard for digital fingerprinting that produces 20:1 compressed images (Cipra, 1993). Wavelet theory can also be applied to many other types of data including sound, text, and generic data.

Future telemedicine technologies used by the U.S. Navy should make full use of these innovative compression techniques which promise to alleviate some of the miltarytelemedicine's current bandwidth problems.

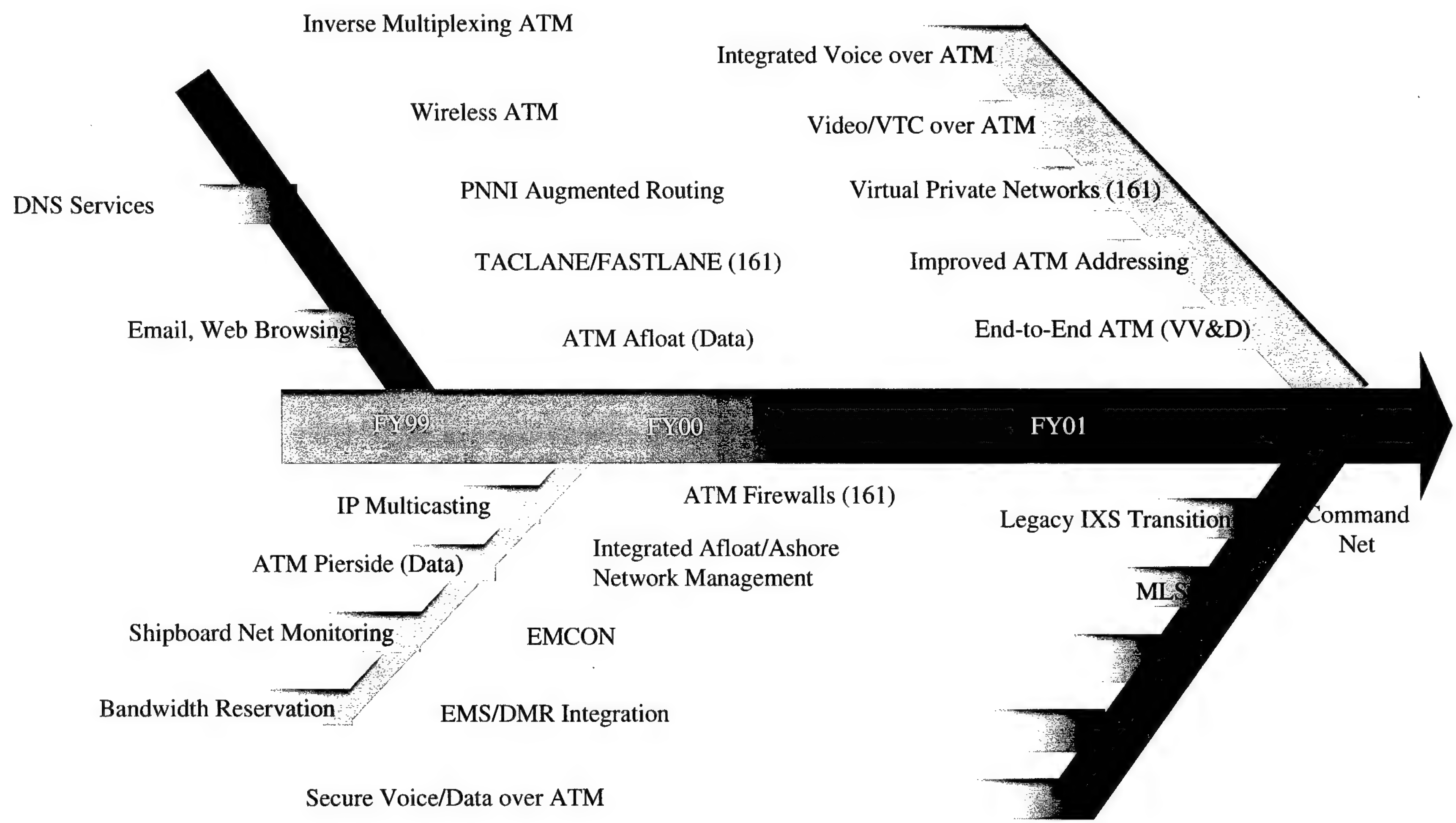

Figure 13. Current trend thrusts toward integration of Modular Robust Technologies.

LONG-TERM ENHANCEMENTS

Many emerging technologies may have an important effect on telemedicine. These technologies include advances in high data rate communications and in multifunction communications systems.

Modern battle groups must share large amounts of targeting, tactical and administrative data in real time, contraining the availability of assets to support telemedicine. Current communications are limited in their ability to transfer data within the allowed frequency spectrum, which is shared, in part, with commercial and radar users. The high-frequency region of the spectrum (2 GHz to 90 GHz) offers a more sparsely populated electromagnetic region and an opportunity for high data rate (HDR) communications. However, RF communications (greater than about 10 GHz) suffer from atmospheric effects such as attenuation caused by fog and rain, LOS blockage, and absorption by atmospheric oxygen (above 60 GHz) (Schlosser, 1996). Despite these effects, microwave and millimeter bands can provide the U.S. Navy with digital communications and data rates from 1.544 Mbps (T1) to 225 Mbps. A point-to-point network operating at less than 30 GHz can provide video teleconferencing (VTC) from ship-to-ship or ship-to-shore (North et al., 1995).

Recent advances in solid-state lasers have increased interest in laser communications. Laser communications offer very high data rates (VHDR) (greater than 1 Gbps have been demonstrated) (Bloom, Chan, and Liu, 1995) with a low probability of intercept or detection (LPI/LPD). Therefore, there are no bandwidth limitations for any aspects of telemedicine, as the high data rate can accommodate VTC, large file transfers, and high-resolution images and video. The U.S. Navy has investigated several laser communication systems during the last three decades (Lovern and Poirier, 1997). These systems include demonstrations of LOS ship-to-ship, aircraft-to-underwater submarines, and intentionally short-range communications. Demonstrations by the Naval Command, Control and Ocean Surveillance Center (now SSC San Diego) included an 8-km link during the AFCEA West Conference in 1995 that transmitted high-resolution video at 560 Mbps over one channel and ATM computer network traffic with a data rate of 155 Mbps (OC-3) over a second channel. The ATM backbone provided a network connection that carried a minimum of three simultaneous VTC sessions. The two channels were optically multiplexed, thus providing an aggregate data rate of 715 Mbps. The Ballistic Missile Defense Organization (BMDO) has an ongoing program to develop intersatellite and theater air operations laser communications. Under this program, a VHDR link over a distance up to 150 km was demonstrated at 1.13 Gbps with a bit-error-rate (BER) of 10^{-6}. This demonstration showed live video (at 560 Mbps) simultaneously with digital data (transmitted at 570 Mbps) (Lovern and Poirier, 1997).

Laser communications systems are now commercially available for building-to-building communications links and fiberless networking. Examples can be found at the AstroTerra Corporation web site (AstroTerra Corporation, 2000) and the AirFiber, Inc. of San Diego, California, web site (AirFiber, 2000). The AstroTerra Corporation has demonstrated point-to-point free space optical links at 155 Mbps (OC-3) over a distance of 500 m with 99% availability. AirFiber, Inc. has has demonstrated data rates of 622 Mbps (OC-12) in a nearly omnidirectional system at short ranges (about 200 to 500 m) with 99.999% availability. The high availability is achieved using an optical mesh architecture to route the signal to an available node. The disadvantages of laser communications is that it is not "all weather." The general rule of thumb is that the link will operate slightly farther than the optical visibility distance; however, communication architectures that back up the VHDR laser communication system with a HDR RF link could provide an adaptable system that ccould provide an enormous bandwidth for telemedicine requirements.

The Defense Advanced Research Projects Agency (DARPA) Special Projects Office initiated the Reconfigurable Aperture (RECAP) program in 1999 (DARPA, 2000a). RECAP provides a single

radiating element (i.e., antenna, ground plane, balun, feedline, etc.) that can perform multiple functions. This element may entail, for example, changing frequency bands, changing polarization, adaptive beam forming and beam steering. Many systems under development use Microelectromechanical Systems (MEMS) technology or microelectronic switching elements to change the electrical size of the antenna, the position of the ground plane, and the position of the feed to optimize performance for different applications. Telemedicine is relegated to a relatively low priority for access to U.S. Navy communication systems during times of conflict. Therefore, the use of a multifunction antenna enabled by RECAP technology could alleviate this problem. Multifunction antennas would reduce the number of antennas onboard U. S. Navy ships and other platforms, thereby providing additional physical space (and electromagnetic spectrum allocation) to mount antennas or systems dedicated (at least, in part) to telemedicine. Secondly, RECAP systems could be actively reconfigured to provide telemedicine support in-between periods of high usage of communications resources.

The DARPA Microsystems Technology Office initiated the Steered Agile Beam (STAB) program in 2000 (DARPA, 2000b). The goal of STAB was to develop novel technologies for miniaturizing active beam steering of optical beams (such as lasers). Such a technology investment may be the enabling technology for VHDR optical/laser communications on mobile platforms. This technology could could extend telemedicine from larger ship or shore-based platforms to air and ground vehicles used by the U.S. Navy, Marine Corps, Air Force, and Army.

PROPOSED ARCHITECTURES FOR NAVAL TELEMEDICINE

Communications technology requires systems that can be adapted to or enhanced by new technological advances.This section describes alternative architectures for U.S. Navy telemedicine services.

ADAPTIVE SYSTEMS FOR A TELEMEDICINE ARCHITECTURE

This architecture is based on a study (Chimiak et al., 1997) published in 1997 that describes the concepts and technologies necessary to establish a U.S. Navy telemedicine system. The proposed system contains the following components: Fleet Naval Medical Consultation and Diagnostic Centers (FNMCDCs); Shipboard Naval Medical Consultation and Diagnostic Centers (SNMCDCs), which can be any hospital or combatant ship with an MTF; and Remote Medical Referring Centers (RMRCs) such as a field hospital, a naval station annex, or a ship. This naval telemedicine architecture uses computers, video teleconferencing systems, or telephone systems to deliver medical care and education, and to enhance their quality by providing access to research tools, medical imaging, remote consultation, and patients' medical information. This new system provides the infrastructure to integrate all the medical information required and disseminate it among the teleparticipants. The proposed architecture will demonstrate and implement a more cost-effective telemedicine service and will provide medical staff with an enhanced diagnostic tool, such as a telepathology system. This new architecture will process and transmit information in a reliable and reproducible manner, allowing medical staff to provide better health care and minimizing the medical and legal implications of a possible misdiagnosis. The standards used in teleconferencing applications have already been developed by the International Telecommunications Union-Telecommunications (ITU-T). These standards promote interoperability, making it easier to deploy various compatible units as required. Table 21 lists some of the most important standards.

The proposed telemedicine workstations support several telemedicine disciplines. Their use by different specialty areas can be monitored by a decision-making central station that adaptively deploys more resources or stations to the more demanding areas at any given time. The cost is greatly reduced when compared with the cost of permanently assigning a unit to a given medical specialty or section. Another advantage of these less-expensive telemedicine workstations is that they can be placed in many more strategic locations, readily accessible to a medical staff rather than a single telemedicine room that may not be in a very convenient location. Another adaptive feature will be that the telemedicine workstation will function according to requirements of the medical staff. When a physician, nurse, or technician logs on to the workstation, its functions are altered to meet special user needs. As with any other sophisticated telemedicine system, this system allows sharing broadcast-quality video, vital sign telemetry, and retrieval of data from a patient's electronic records.

A prototype of this system, without the GUI, was demonstrated at the Armed Forces Institute of Pathology's Telemedicine'95 Conference in Washington, DC, 4–11 January 1995, and also at the 1994 RSNA Conference in Chicago, Illinois, where a DS-3 ATM link between Chicago and Winston-Salem, North Caroloina, connected early prototypes of these workstations and demonstrated teleradiology and telemedicine services. The innovative concept of this architecture is the possibility of having telemedicine workstations that function as complete hospitals.

Table 21. Important teleconferencing standards promoting interoperability developed by the ITU-T standards section.

Standard	Description
H.320	Visual telephone system standard
H.231	Standard for multipoint control units defining how three or more H.320-compatible systems link together in a single conference.
H.322	An enhanced version of H.320 optimized for networks that guarantees QOS for isochronous traffic as a real-time video.
H.323	H.323 extends H.320 to Ethernet, Token-Ring, and other packet switch networks that do not guarantee QOS; it will support point-to-point and multipoint operations.
T.120	T.120 covers document sharing protocols; whiteboard applications are covered in this standard.

The U.S. Navy telemedicine architecture serves three main organizations: FNMCDC, SNMCDC, and RMRC. These organizations provide different services and use different types of telemedicine workstations. The workstations not only adapt to the user's specialty and requirements, but also to the medical task requested and the available bandwidth. The architecture uses a dynamically adaptive multidisciplinary workstation (DAMDW) that presents few options, which makes it easy to use.

The support core of the naval telemedicine architecture consists of the tertiary-care naval hospitals, the FNMCDCs, and the SNMCDCs. The SNMCDCs support the RMRCs for ship-to-ship communications (figure 14). The FNMCDCs support the RMRCs for ship-to-shore communications (figure 15). The full FNMCDCs use DAMDWs with the following subsystems: teleradiology, telemedicine, telepathology, and an informatics system that provides integrated access to standards-based systems such as the Health Level Seven (HL-7) hospital information systems. HL-7 is one of the most popular methods of integrating existing hospital information systems.

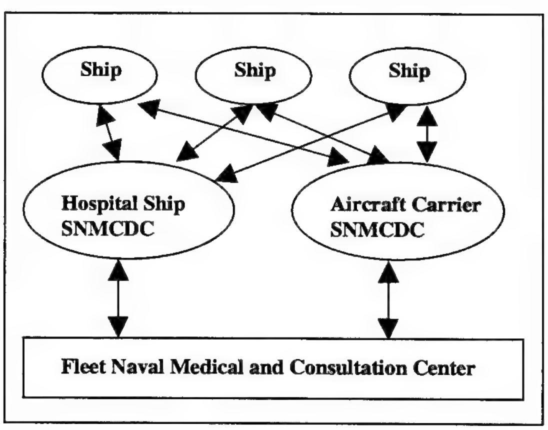

Figure 14. RMRCs and SNMCDCs supported by FNMCDC.

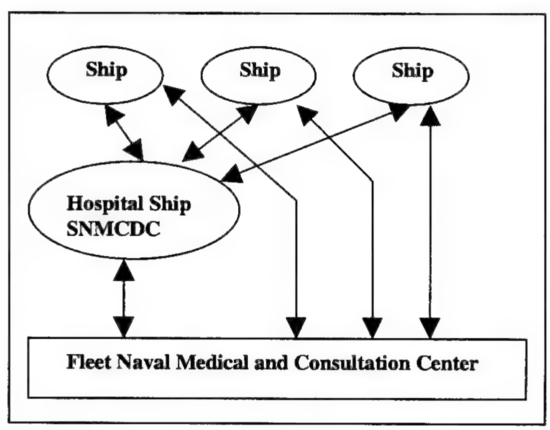

Figure 15. DESRON RMRCs supported by FNMCDC.

DESCRIPTION

Subsystems for the Naval Telemedicine Architecture

The followiong subsystems are for the Naval Telemedicine Architecture:

- **Teleradiology Subsystem.** This subsystem supports diagnostic and consultative digital radiology, usually from a remote site to a radiology department. The subsystem is expandable to support direct or networked radiograph filming with very flexible interfacing capabilities. The system can also be upgraded to a picture archiving and communication system (PACS).
- **Telemedicine Subsystem.** This subsystem supports telediagnosis procedures including general internal medicine examinations such as eyes, ears, nose, throat, etc.
- **Telepathology Subsystem.** This subsystem supports anatomic pathology and cytology without the intervention of robotic systems, providing the same functionality, at 1/10th the cost, as the robotic systems such as the Roche telepathology system. In the telepathology subsystem, a member of the medical staff onboard the RMRC takes a mounted slide and places it on the microscope, which allows the FNMCDC pathologist to observe the slide using low-resolution imaging. Once a problem or an area of interest is identified, a high-resolution image is presented to the FNMCDC pathologist for more careful analysis. An iterative process continues until a diagnosis is made.

The Naval Telemedicine Architecture supports various levels of security, from those found in UNIX system to those found in custom telephone systems. This proposed architecture can communicate with various off-the-shelf naval computers such as SUN, SGI, and x86-based workstations. The degree of security in UNIX workstations can be enhanced by using password aging, Kerberos computer security, data encryptions, and data link layer encryptions schemes.

Advantages of the Naval Telemedicine Architecture

Advantages of the Naval Telemedicine Architecture include the following:

- FNMCDC DAMDW is a scalable system that can be adapted to a specific task, lowering the cost for training and logistics when compared with systems made up of dissimilar components.
- DAMDW will interface in the same way, regardless of the specific hardware infrastructure used.
- Remote maintenance and troubleshooting can be performed on UNIX DAMDW systems using different levels of security.
- DAMDWs are easily configured to support a RMRC, an FNMCDC, or an SNMCDC. The RMRC can be supported either by the SNMCDC or the FNMCDC. See figures 14 and 15 respectively.
- DAMDWs can be specified to cover a limited number of functions, lowering the acquisition cost but retaining expansion capabilities. This feature provides an evolutionary path toward a full FNMCDC.

Benefits of the Naval Telemedicine Architecture to a RMRC and an SNMCDC

Benefits of the Naval Telemedicine Architecture to a RMRC and an SNMCDC include the following:

- Enhanced shipboard medical services
- A reduced number of MEDEVACs and associated cost (this is accomplished by providing a more precise diagnosis onboard)
- A continuous availability of academic medical center educational and clinical expertise
- Educational opportunities available on a continuous basis

Benefits of the Naval Telemedicine Architecture to an FNMCDC

Benefits of the Naval Telemedicine Architecture to an FNMCDC include the following:

- Extends the clinical and educational expertise of the FNMCDC to remote locations
- Minimizes or eliminates travel to tertiary-care facilities
- Extends to other multimedia training for the Fleet

Services Provided by the Naval Telemedicine Architecture

The Naval Telemedicine Architecture provides the following services:

- Pathology
- Telepresence (proctoring) for surgical procedures
- Video-conferenced internal medicine
- Dentistry
- Ultrasonography
- Dermatology
- Psychiatry
- ICU telemetry

Growth Areas for the Naval Telemedicine Architecture

Growth areas for the Naval Telemedicine Architecture include the following:

- Provides flexibility to support any combination of different medical specialties
- Provides the flexibility to support any combination of communication bandwidths depending on the requirements of the procedure
- Provides the ability to support planning its implementation
- Provides the ability to control its evolution to a full system based on available funds or medical requirement

The FNMCDC could run on workstations from different companies such as Sun Microsystems, Hewlett Packard, IBM, Digital Equipment, Silicon Graphics, or any PC. HL-7 is being deployed by hospitals and is also being adopted by AGFA, Cemax, and Lockheed/Martin as an interface language for their PACS. The Naval Telemedicine Architecture is adaptable to existing and emerging technologies and can be upgraded with a minimum replacement of components, maximizing the lifetime of the system. X-Windows is used for imaging and viewing. The following Internet protocols are used for communications:

- Transmission Control Protocol and Internet Protocol (TCP/IP). Digital Imaging and Communications services in Medicine (DICOM) rely on TCP/IP for data transmission
- User Diagram Protocol (UDP)
- Point-to-Point Protocol (PPP)
- Other Internet Engineering Task Force protocold for emerging ATM technologies

The Internet Protocol provides connection with any of the following standard sites:

- DoD DARPA Internet
- DoD Internet
- University Internet
- Commercial Internet
- TCP/IP Intranet

This Naval Telemedicine Architecture can use existing technology and also adapt to emerging technologies such as ATM switches, allowing higher speeds and bandwidths. This increase could be a very important factor for real-time clinical ultrasound and fluoroscopy applications that may require ATM technologies.

PACS ARCHITECTURE

PACS can be used to develop an entire architecture for a naval telemedicine system. In this architecture, each U.S. Navy ship and shore site will have a U.S. Navy PACS (NPACS) system connecting workstations aboard a ship's MTF with those located at medical shore facilities. The equipment required for this type of architecture was listed in a previous chapter and includes the following:

- **Remote Viewing Workstations.** IDCs will use workstations to acquire images from radiology and dermatology sessions, vital signs, and other patient information.
- **Local Viewing Workstation.** Medical staff at medical centers, such as the Navy Medical Center San Diego, will use workstations to provide medical consultation services in the interactive remote telemedical consultation.
- **Database Archive System.** UNIX-based systems will be used for multimedia storage and archiving of medical records, images, voice, video, text, etc. They will include a management system that will allow for storage and retrieval of multimedia objects used in telemedicine applications. A system could be placed, for example, at the NHRC facility in San Diego.

- **Portable Workstation.** Workstations are to be used in space-limited ships such as submarines, frigates, and destroyers. Portable workstations will be more limited than the other workstations but will still include image viewing, vital signs, and patient information.

The remote and local viewing workstations have multimedia interfaces and operate in an Windows NT® environment. Figure 8 shows the interconnection for possible sites involved in this architecture. This architecture would provide the following services:

- Transfer of vital signs data
- Ability to store and forward images from radiology, dermatology, and pathology sessions
- Videoconferencing capabilities
- Real-time voice data
- Access to patient medical records and information
- Capability for remote consultation and diagnosis sessions
- Access to online medical information

Figure 11 shows the mechanisms for transmitting and receiving information between the MTFs and NPACS. In these mechanisms, telemedicine systems are considered a User Segment (US) and include the NPACS network, image, video, and the equipment used for vital signs acquisition. The hardware to interface with the Platform Distribution System (PDS) is also included. The PDS includes routers that distribute the information to the corresponding Channel Access Protocol (CAP) unit. Finally, these CAPs connect the U.S. Navy communications system for that channel in the Resource Segment (RS). This RS can provide a SATCOM, LOS, or BLOS connection. The receiving end can be a U.S. Navy ship or the communications system at a shore facility such as SSC San Diego. The telemedicine gateway at SSC San Diego serves as a router to disseminate the information through terrestrial networks such as the one at the Navy Medical Center San Diego. Figure 16 shows the equipment of a typical MTF facility aboard a U.S. Navy ship. Terrestrial connections can be made using a T1 link or an Internet link.

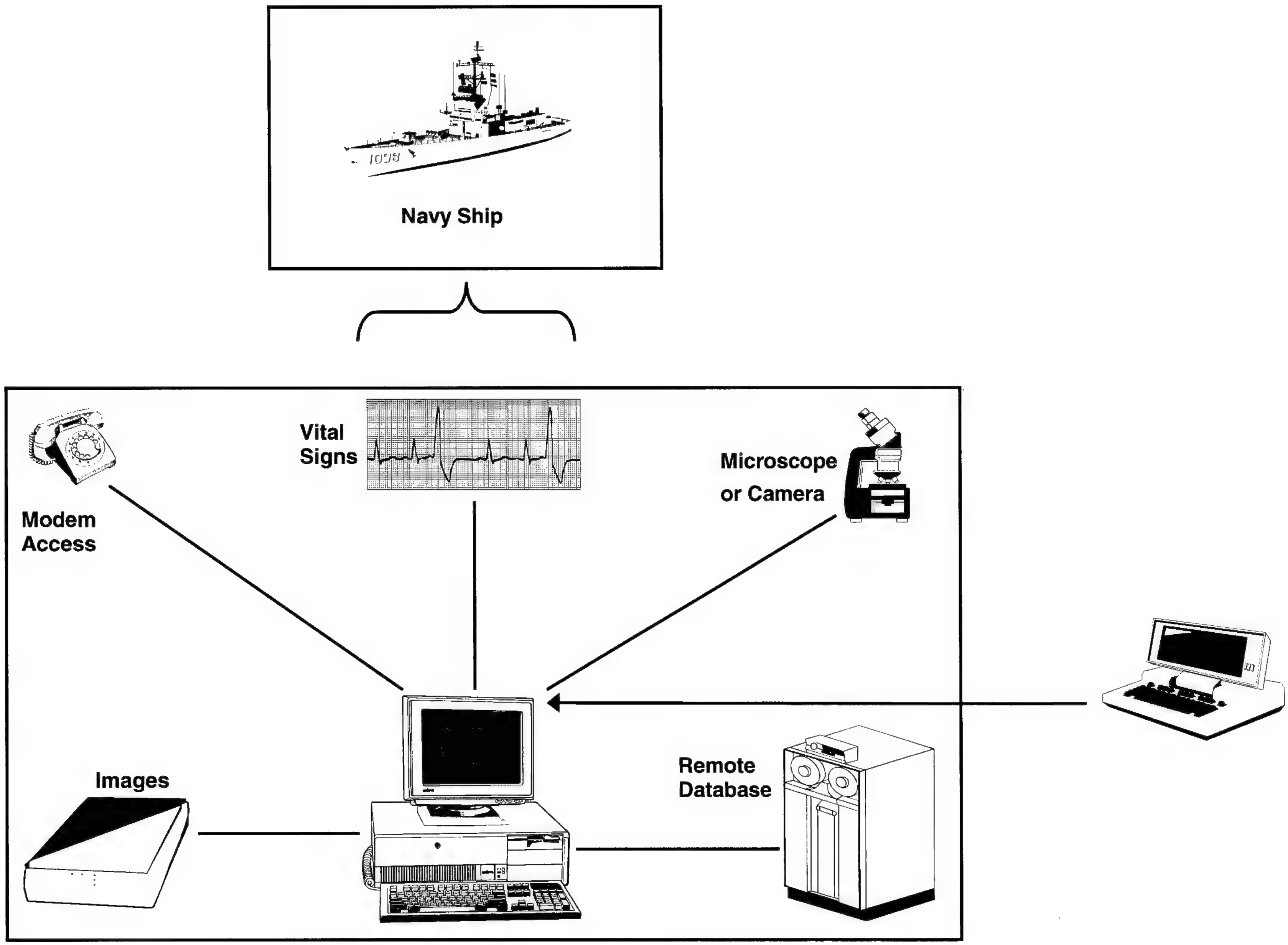

Figure 16. Equipment aboard a ship's MTF Remote Workstation.

COTS TECHNOLOGY FOR AN ARCHITECTURE

A basic telemedicine architecture can be implemented using only COTS technology. One example of commercial telemedicine technology is the Automated System for Patient Record and Information (ASPRIN), sold by HealthCom, Inc., San Diego, California. This system is a modular architecture that accommodates the COTS items described in tables 22. The architecture supports several telemedicine applications and the scalable communications structure described in table 23. This system's communications structure can be adapted to different communications systems.

Table 22. Modular architecture for telemedicine COTS technology.

	MODULAR ARCHITECTURE	
	Module Description	Type of Connection
	Audio stethoscope	
UNIX	Video ultrasound, ENT	BNC, RCA
NT	2K x 2K displays	Sbus
	Scanner, printer, 35-mm slides	Parallel
	Monitors	Serial
	CD-ROM, tape, optical jukebox, RAID storage	SCSI

Table 23. Scalable communications for the telemedicine COTS architecture.

	Scalable Communications	
	CSU-DSU →	Cellular (56 Kbps)
Network		ISDN (128 Kbps)
Support	→	Internet, T1 (1.544 Mbps)
		FDDI (100 Mbps)
	Fiberoptic LAN →	Switching to WAN

GOTS TECHNOLOGY FOR AN ARCHITECTURE

DoD sponsors the following programs involving telemedicine or telemedicine technology:

- Medical Diagnostics Imaging System (MDIS), U.S. Army Materials Command
- Medical Advanced Technology Management Office (MATMO) Telemedicine Test Bed
- Joint Warrior Interoperability Demonstrations (JWID) in Telemedicine. The following is a summary of the recommendations for communications, networking, and Navy telemedicine systems. This summary is a result of the lessons learned in the JWID programs (Chairman of the Joint Chiefs of Staff, 1998):

  1. Dynamic routing must be used for DoD Internet Protocols (IPs).
  2. A common router interface suite must be adopted.
  3. A dual hub must be used whenever resources are available.
  4. A secret level Domain Name Service (DNS) should be established.
  5. Review security policy and technology that presently inhibit communications improvements.
  6. Allocate greater bandwidth to data circuits during tactical Joint Task Force (JTF) deployments.
  7. Test Integrated Digital Network Exchange (IDNX) links with Joint Force Air Component Commander (JFACC), Wing, Army Forces (ARFOR), and Marine Forces (MARFOR) for standard configuration.
  8. Provide necessary tools for the Joint Combat Camera Center (JCCC) by using a Joint Communications Planning and Management System (JCPMS).
  9. Incorporate tactical interface training in existing IDNX training courses.
  10. Use packed-based encryption devices to use ATM networks more efficiently.
  11. Require Trunk Encryption Device (TED) resynchronization capability on ATM switches and routers for use with Defense Satellite Communications System (DSCS) links.
  12. Standardize ATM technology for full integration.
  13. Require coordination between the National Telecommunications and Information Agency (NTIA) and civil authorities to review procedural issues with "C" band transmission.
  14. Provide ground entry stations to terminate "C" and "Ku" transmission bands ground entry points under the commercial SATCOM initiative.
  15. Study the trend of using smaller satellite dishes that demand more transponder power.
  16. Update and improve Line of Termination Unit (LTU) documentation.
  17. Large and complex IP networks should refrain from over-using Protocol Internetwork Grouper (PING) to check for network connectivity.
  18. Provide a network manager with centralized polling and distributed database capabilities.
  19. Recommend eagle and outpost gateways for immediate operational use.

20. The Navy and the Defense Intelligence Agency (DIA) must resolve the assignment of Joint Worldwide Information Communications System Defense Secure Network 3 (JWICS DSNET3) compatible IP addresses.

A JWID-related demonstration in telemedicine was held in September 1995 between Balboa Medical Center and Camp Pendleton. Physicians at Balboa Medical Center reported several problems with the equipment. This demonstration emphasized the importance of integration and compatibility in the architecture of communications systems used for telemedicine applications.

MEASURABILITY

Sets of agreeable and specific metrics are always an issue where complex organizational structures exist. This applies within and across the telemedicine services. During RIMPAC 2000, the Third Fleet used three tests to measure the effectiveness of care. The test questions for measurability were reformulated after the RIMPAC 2000 exercise. Some important measurability tests are as follows:

1. Characterization of the communications systems:
   a. Does it meet bandwith requirements?
   b. Does it have an acceptable error rate?
   c. Is it robust?
   d. Is it able to transmit information at an acceptable speed?
2. Effectiveness of forward information transfer:
   a. Can a medic get far-forward casualty information to the Task Force Surgeon?
   b. Can a medic get helpful information?
3. How well does the information get to the right place?
4. What are the impacts of the information?
   a. Does the information affect the delivery of care?
   b. Does the data include useless information?
   c. Is the critical amount of information included?
5. How accurate is the information input (from data entry point)?
   a. Is the right kind of data interface being used?
   b. Does the interface beat paper?
6. Ability to quickly document:
   a. Are there cumbersome pull-down menus to get to data fields?
   b. Can a medic just talk to the interface?
   c. Does data entry compete with delivery of care?
7. How well does the system integrate with other methods (i.e., hybrid of paper/computers)?
8. Are there elaborate training requirements to operate the interface?
9. Is the telemedicine system feasible from a reliability and maintainability perspective?
10. Costs?

The specific metrics themselves are not necessarily right or wrong. The main idea is that whatever final measurability tests are selected and implemented, they should enable a decision-maker to answer whether, per unit energy, the telemedicine solution applies more medical expertise to patients' needs or whether it is encumbered by its own weight. The metrics should also be applicable to simulations and live demonstrations to give analysts enough information to select the best method before Navy-wide implementation.

CONCLUSIONS

This report summarized critical results obtained from several studies on communications, capabilities of the medical treatment facilities, and telemedicine technologies used aboard U.S. Navy ships. Part of the effort in compiling this report was coordinated with Third Fleet personnel aboard USS *CORONADO*. U.S. Navy communications resources were described in detail and certain issues regarding the management of those resources were addressed. This report also described U.S. Navy communication system protocols and multimedia services. An important section discussed the role of the Internet in U.S. Navy telemedicine applications; it described some technical challenges and possible solutions in enhancing and fully implementing telemedicine services over the Internet. Functional and technical requirements and enhancements to current technologies were addressed. This report proposed four telemedicine architectures that included COTS and GOTS technologies, PACS, and adaptive systems. Measurability parameters were defined and recommendations are provided that advance telemedicine science.

An important result from the studies in medical communications is that, on the average, a U.S. Navy ship initiates two medical communications per year and two medical evacuations (MEDEVACs) per year. Ships with a physician aboard averaged 1.5 MEDEVACs per 1000 patient visits; those with an Independent Duty Corpsman averaged 3.5 MEDEVACs per 1000 patient visits. Almost one-third of the cases that resulted in a MEDEVAC could have been avoided if better telecommunications capabilities had been available. Minimizing the number of MEDEVACs without sacrificing the health care of the patient is very important. A lower number of MEDEVACs will improve mission readiness and reduce costs for the U.S. Navy. Study results indicate that a reduction in MEDEVACs could be accomplished by placing a physician aboard every U.S. Navy ship and still lead to substantial cost savings.

The competition for bandwidth is probably the most important issue faced by the telemedicine community. The availability of bandwidth under different situations is a complex problem with no current solution. This report proposed several ways to manage bandwidth resources. One suggestion is to provide an infrastructure that uses every opportunity to update information in the local database as a temporary stand-alone unit system onboard. Another strategy is to prioritize the classes of telemedicine operations to be conducted when bandwidth becomes available. For example, after threat conditions decrease, telemedecine systems can be brought back on in layers. The Navy-wide use of Ku band systems and CDL requirements could also enhance bandwidth capabilities, aiding in the management of all available resources.

Great advances in Internet technologies provide access to health records, online consultations, real-time video connections, and useful sites such as the VNH and the GHNet. One of the most challenging problems faced by Internet providers is the implementation of the proper protocols for QOS to guarantee users the availability of bandwidth and latency across the network. Exploiting the WDM concept, possible solutions include the wide use of optical fiber links to increase bandwidth capacity. A limiting factor in implementing this technology has been the cost of equipment such as SONET, termination equipment, routers, and switching devices. Differential and integrated services mechanisms are presently being implemented to guarantee customers that their information will get to its destination in a prompt and complete manner. In addition to the QOS mechanisms, a broadcast model is currently being developed that will use available bandwidth more efficiently. Implementation of these services in U.S. Navy telemedicine systems must be considered for terrestrial applications.

This report defined functional and technical requirements. Functional requirements included medical administration, radiation health, occupational and environmental health, medical encounters, and supply issues. Technical requirements, specifically, bandwidth requirements, were defined for different U.S. Navy telemedicine services. These requirements can now be matched with the bandwidth capability of current U.S. Navy communications systems or with the capabilities of enhanced and future technologies. A study must be conducted to compare current and future technologies and determine how these technologies can be integrated into existing U.S. Navy communications systems.

An important part of this report described near- and long-term enhancements to the technology currently used in U.S. Navy telemedicine communications systems. Emerging technologies such as CRM technology can have a substantial impact on U.S. Navy telemedicine. Many telemedicine systems have been demonstrated aboard USS *CORONADO* during Rim of the Pacific (RIMPAC) Humanitarian Response Exercises 2000. Strong Angel was conducted June 2000 as part of RIMPAC 2000, which conducted two experiments: (1) one-way information translation and a two-way interactive information translation component, an interactive paging system, and a demonstration of alternative power concepts, and (2) distribution of medical communications, civil–military interactions and communications, and a humanitarian information management element. Transitioning technologies from the DAWN project such as the concepts of wearable computers, and I/O enhancements were also described. New data compression techniques such as wavelet algorithms were also addressed. Long-term enhancements include laser communications, RECAP using MEMS, and miniaturizing active beam-steering mechanisms for laser communications. These long-term enhancements could completely change the way in which information is transmitted and could greatly improve the overall capability and reliability of U.S. Navy telemedicine systems. These new near- and long-term concepts and technologies must be studied in more detail and a test bed must be established to prove their feasibility.

The architectures proposed in this report solve, at least in part, some of the problems faced by the U.S. Navy telemedicine community. The adaptive systems described will be scalable systems that can be adapted to a specific task, lowering the cost for training and logistics. These systems will enhance shipboard medical services and lower the number of MEDEVACs and their associated cost. They also provide the flexibility to support any combination of different medical specialties and communication bandwidths, depending on the requirement of the procedure. These systems will also adapt to emerging technologies, allowing higher speeds and bandwidths. The concept of the global PACS architecture was also described. In this architecture, each U.S. Navy ship and shore site will have a NPACS system connecting workstations aboard a ship's MTF with those located at medical shore facilities. The use of COTS and GOTS were also addressed in the proposed architectures. These architectures alleviate some of the problems encountered in providing telemedicine services over U.S. Navy communications systems without sacrificing the health care delivered to the warfighter and with minimal disruption of mission readiness status.

Whatever systems or architectures are used in future U.S. Navy telecommunications, they must possess the following characteristics:

- Adapt to different situations (combat, non-combat) under which requirements may be different
- Switch to different requirements (such as bandwidth)
- Support different medical specialties (medical flexibility)
- Prioritize different medical services under different conditions

- Provide flexibility to grow and be enhanced by using emerging technologies
- Be cost effective
- Be simple to use by any medical or other technical staff

RECOMMENDATIONS

This report has identified clear actions that will aid in the wider implementation of telemedicine in the U.S. Navy, Navy extensions, interfaces to DoD, coalition forces, and the civilian sector. These actions include the following:

1. Provide an independent critical review of the existing disparate telemedicine solutions using laboratory and field-testing studies
2. Develop a telemedicine implementation roadmap spanning all U.S. Navy assets and extending through joint coalition forces
3. Provide a mechanism for collecting telemedicine-related information that is developed in various technical communities and disseminate the information to all interested parties
4. Establish an impartial test bed to evaluate new technologies and systems; this test bed can examine feasibility under various operational scenarios (peacetime and wartime) and prioritize solutions; the test bed may also serve as a conduit for the transition of technology to the Fleet
5. Identify a capable technical agent that can assist in program management
6. Evaluate, demonstrate, and transition emerging technologies
7. Actively implement all the above recommendations

LIST OF ACRONYMS

AD, AGF, AOE, AOR, AS	Auxiliary Ship Class
AFCEA	Armed Forces Communication and Electronics Association
ARFOR	Army Forces
ASPRIN	Automated System for Patient Record and Information
ATM	Asynchronous Transfer Mode
ATMAAL	Asynchronous Transfer Mode Application Adaptation Layer
BER	Bit Error Rate
BLOS	Beyond Line of Sight
BMDO	Ballistic Missile Defense Organization
BP	Blood Pressure
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAP	Channel Access Protocol
CD	Compact Disc
CDL	Common Data Link
CFS	CRM Forwarding Service
CG	Cruiser
CODEC	Compression/ Decompression
COMSAT	Communication Satellite
COTS	Commercial off the Shelf
CR	Computerized Radiography
CRM	Collaborative Reliable Multi-Cast
CSS	Communication Support System
CT	Computerized Tomography
CVN	Aircraft Carrier Class
DAMA	Demand Assignment Multiple Access
DAMDW	Dynamically Adaptive Multidisciplinary Workstation
DARPA	Defense Advanced Research Projects Agency
DAWN	Demonstration of Advanced Wireless Networks
DC	Dental Corps
DCT	Direct Cosine Transform
DD	Destroyer
DER	Distributive Error Recovery
DIA	Defense Intelligence Agency
DMR	Digital Modular Radio
DNS	Domain Name Service
DoD	Department of Defense
DSCS	Defense Satellite Communication System
DSNET	Defense Secure Network
DT	Dental Technician
ECG, EKG	Electrocardiogram
EHF	Extremely High Frequency
FFG	Frigate
FLT-SATCOM	Fleet Satellite Communication
FMFM	Fleet Marine Force Manual
FNMCDC	Fleet Naval Medical Consultation and Diagnostic
GHNet	Global Health Network
Gbps	Giga-bits per second
GOTS	Government off the Shelf
GUI	Graphical User Interface
HAMA	Hand-off Assigned Multiple Access
HC	Hospital Corpsmen
HDLC	High Level Data Link Control
HDR	High Data Rate
HF	High Frequency
HMO	Health Maintenance Organization
HR	Heart Rate
HSS	Health Service Support
IC4I	Integrated Command, Control, Communications, and Computer Intelligence
ICU	Intensive Care Unit
IDC	Independent Duty Corpsmen
IDNX	Integrated Digital Network Exchange
IETI	Internet Engineering Task Force
INMARSAT	International Maritime Satellite
INTELSAT	International Telecommunications Satellite
IP	Internet Protocol

ISDN	Integrated Services Digital Network
ISO	International Standards Organization
ISP	Internet Service Provider
ITU	International Telecommunication Union
JCCC	Joint Combat Camera Center
JCPMS	Joint Communication Planning and Management System
JFACC	Joint Force Air Component Commander
JPEG	Joint Photographic Experts Group
JTF	Joint Task Force
JWICS	Joint Worldwide Information Communication System
JWID	Joint Warrior Interoperability Demonstration
Kbps	Kilo-bits per second
KBX	Kernel Blitz Experimentation
LAP	Link Access Protocol
LHA, LHD	Amphibious Assault Ship Class
LCC	Amphibious Command Ship Class
LDR	Low Data Rate
LF	Low Frequency
LCAC	Landing Craft Amphibious
LOS	Line-of-Sight
LPD	Amphibious Transport Dock Class
LPI/LPD	Low Probability of Interception/Detection
LSD	Dock Landing Ship Class
LTU	Line of Termination Unit
MARFOR	Marine Forces
MASH	Mobile Army Surgical Hospital
MATMO	Medical Advanced Technology Management Office
Mbps	Mega-bits per second
MC	Medical Corps
MCA	Multi-Channel Architecture
MDIS	Medical Diagnostic Imaging System
MDR	Medium Data Rate
MEDEVAC	Medical Evacuation
MEMS	Micro-Electro Mechanical Systems
MF	Mid-Frequency
MONET	Mobile Network
MPEG	Moving Picture Experts Group
MRI	Magnetic Resonance Imaging
MSC	Military Sealift Command
MTF	Medical Treatment Facility
NASA	National Aeronautics nd Space Administration
NC	Nurse Corps
NECC	Navy EHF Communications Controller
NHRC	Naval Health Research Center
NIH	National Institute of Health
NIPRNET	Unclassified-but-Sensitive Internet Protocol Router Network
NLM	National Library of Medicine
NRC	National Research Council
NTIA	National Telecommunication and Information Agency
NVH	Naval Virtual Hospital
OR	Operating Rooms
PACS	Picture Achieving and Communication System
PDS	Platform Distribution System
PING	Protocol Inter-Network Grouper
POP	Point of Presence
PPP	Point-to-Point Protocol
QOS	Quality of Service
RECAP	Re-configurable Aperture
RIMPAC	Rim of the Pacific
RCCS	Remote Clinical Communication System
RCD	Remote Consultation and Diagnosis
RF	Radio Frequency
RM	Reliable Multicast
RMRC	Remote Medical Referring Center
RS	Resource Segment
RSNA	Radiological Society of North America
RX	Receive

SAC	Subnet Access Control
SATCOM	Satellite Communication
SHF	Super High Frequency
SIPRNET Network	Secret Internet Protocol Router
SINCGARS	Single Channel Ground and Airborne Radio System
SLIP	Serial Link Internet Protocol
SNMCDC	Shipboard Naval Medical Consultation and Diagnostic
SONET	Synchronous Optical Network
SPAWAR	Space and Naval Warfare Systems Command
SSC San Diego	SPAWAR Systems Center, San Diego
STAB	Steered Agile Beam
TAFIM	Technical Architecture Framework for Information Management
T-AH	Hospital Ship Class
TBD	To Be Determined
TCP	Transmission Control Protocol
TED	Trunk Encryption Device
TEM	Temperature
TMIP-M	Theatre Medical Information Program Maritime
TX	Transmit
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UDP	User Datagram Protocol
VCR	Video Cassette Recorder
VHDR	Very High Data Rate
VHF	Very High Frequency
VON	Virtual Overlay Network
VSAT	Very Small Aperture Terminal
VTC	Video Teleconferencing
WDM	Wavelength Division Multiplexing
WRAMC	Walter Reed Army Medical Center
WSC	Whisky—radio class

GLOSSARY

Algorithm: A computerized method of calculation or computational formula.

Asynchronous Transfer Mode (ATM): A protocol for high speed data transfer.

Availability: The likelihood that a network communication is available or established when requested.

Bandwidth: The data carrying capacity of a network or communication link, usually in bps.

Commercial Off-the-Shelf (COTS): easily accessible, commercially available technology.

Data Rate: The rate at which data are sent across a communication link; usually in bps.

Digitize: To transform analog information into digital or quantized data.

Government-Off-the-Shelf (GOTS): Government-available technology.

Internet Protocol (IP): Standard that regulates computer connections on networks that are part of the Internet.

Jamming: Introducing signal interference as a defense tactic.

Latency: The time it takes a given data packet to travel between point A and B in a communication link, usually between 100 milliseconds to 1 second.

Line of Sight (LOS): A direct line between a transmitter and a receiver, usually LOS communication or direct communication.

NIPRNET: DoD closed network that allows the exchange of sensitive but unclassified material.

Quality of Service (QOS): The capability of a network to meet demands imposed by the user.

Real-Time: Information that is not stored and forwarded, but sent live.

SIPRNET: DoD closed network that allows the exchange of highly sensitive or classified material, Secret Internet Protocol Router Network.

Teleconference: A conference held over a telecommunication link consisting of video and sound, also video-teleconferencing (VTC).

Transmission Control Protocol (TCP): Protocol for data transfer on networks and especially on the Internet.

Ubiquity: The degree of access to a network that describes its limitations; simultaneous users allowed is one aspect.

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This report evaluates the effect current technology has upon the telemedicine aboard U.S. Navy ships while underway. The focus of this report covers current capabilities aboard U.S. Navy vessels for communication operations and for interfacing to existing infrastructure and future technologies. Identifying these capabilities will benefit the acquisition community and those who conduct requirement synthesis where technology proliferates and develops rapidly. This report identifies the communication assets of the fleet infrastructure ashore and at sea, and provides details of functional and technical requirements and possible near- and long-term solutions, enhancements, and recommendations.

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medical communication	casualty collection and treatment	preventive medicine

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